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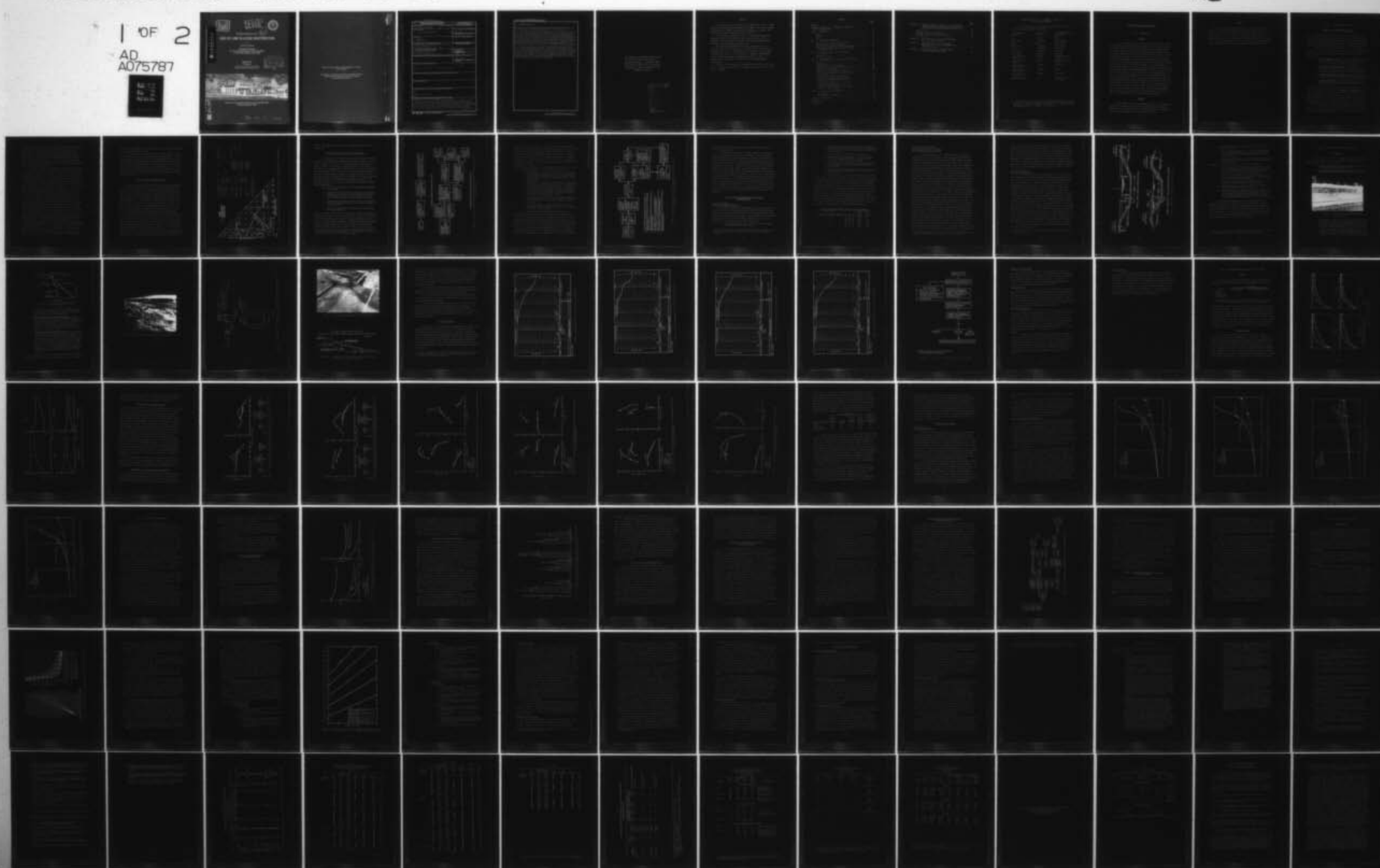

TECHNICAL REPORT GL-79-12

USE OF LIME IN LEVEE RESTORATION

by

Frank C. Townsend

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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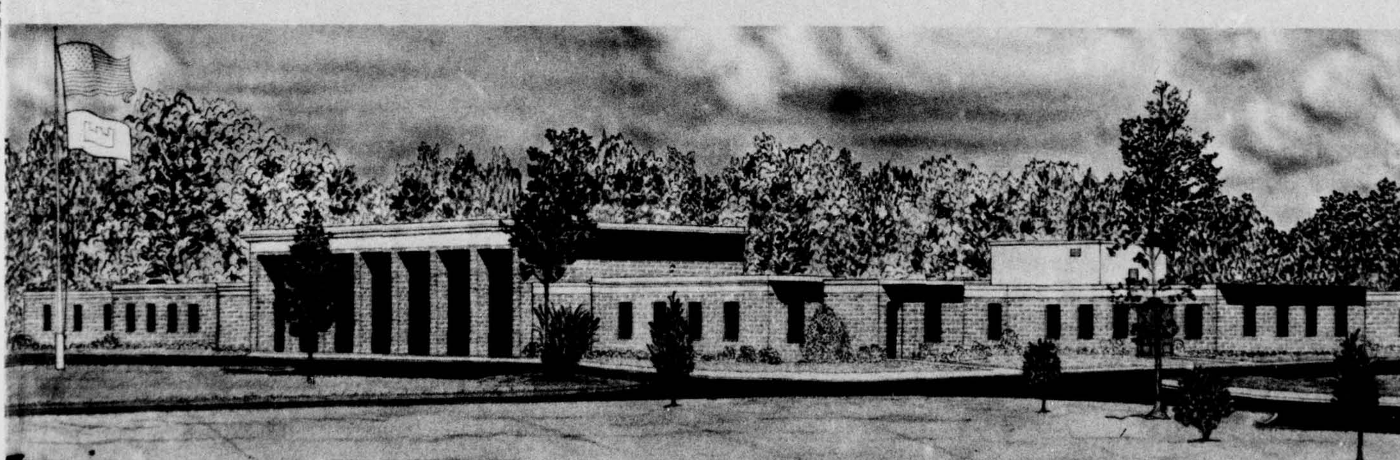

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The objectives of this study were to evaluate the feasibility of lime treatment as an alternative design and remedial method for restoration of shallow surface slides, and furnish criteria for mix design, design parameters, and construction procedures. The lime treatment susceptibility of four typical levee slide clays in the Lower Mississippi Valley Division was evaluated by mix design procedures using pH tests and evaluating effects of normal and

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20. ABSTRACT (Continued).

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accelerated (105°F) curing times, immersion, density and water content, and compaction delay on unconfined compression test (UCT) strengths.

These laboratory test results showed that all of the soils were beneficially modified by the addition of 4 percent lime (pH percentage) and that three of the four soils achieved sufficient strength to be judged reactive to lime stabilization (ΔUCT strength > 3.6 tsf). Delays between mixing the soil and lime and compaction resulted in 30 to 75 percent UCT-strength reductions for delays of 24 hr. However, these UCT-strength reductions due to compaction delay were eliminated by compaction to higher densities. Immersion of UCT specimens caused a total loss in strength for untreated clays, while lime-treated clays had ratios of 0.86 to 0.47 for soaked to unsoaked UCT strengths.

A mix design procedure for assessing the feasibility of using lime for levee slide restoration was developed. The procedure recommends a 28-day normal average UCT-strength increase of 3.6 tsf and a 24-hr immersion strength of 2.12 tsf at optimum conditions as stabilization criteria where strength and durability are critical. Where only soil modification is desired a minimum plasticity index reduction of 50 percent is deemed acceptable, with 28-day strength increases of 100 percent for semicompaction conditions as an optional criteria for judging lime treatment feasibility.

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PREFACE

The investigation reported herein was conducted for the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD). The testing program was authorized by LMVED-G letter dated 12 September 75, subject: WES Investigational Work Program, FY76, FY7T, and FY77.

The testing was performed at the U. S. Army Engineer Waterways Experiment Station (WES) during the period from February 1976 to February 1977 by personnel of the Soils and Pavements Laboratory, now designated the Geotechnical Laboratory (GL).

The study was conducted and the report prepared by Dr. F. C. Townsend, Soils Research Facility, Soil Mechanics Division (SMD), with assistance from Dr. J. W. Spotts and Mr. W. J. Hughes, Soils Research Facility, SMD. Messrs. H. B. Dent and T. V. McEwen, Instrumentation Services Division, provided instrumentation support. Messrs. C. L. McAnear, Chief, SMD, and J. P. Sale, Chief, GL, provided general supervision.

Directors of WES during the investigation were COL G. H. Hilt, CE, COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
square yards	0.8361274	square metres
acres	4046.856	square metres
cubic yards	0.7645549	cubic metres
gallons	0.003785412	cubic metres
pounds (mass)	0.4535924	kilograms
tons (mass)	907.1847	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per gallon	119.8264	kilograms per cubic metre
pounds (force) per square inch	6.894757	kilopascals
pounds (force) per square foot	47.88026	pascals
tons (force) per square foot	95.76052	kilopascals
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

USE OF LIME IN LEVEE RESTORATION

PART I: INTRODUCTION

General

1. The occurrence of shallow surface or slough slides in levees constructed of highly plastic clays represents a continuing and costly maintenance problem to the Lower Mississippi Valley Division (LMVD) districts. While these slides may not necessarily be dangerous, they do create maintenance problems. In addition, if the slide occurs on the riverside of the levee, it is vunerable to scour from the wave wash. Although the mechanisms of failure for these slides in areas that have been relatively stable for many years are not fully documented, possible causes for the reduction in shear strength are (a) weathering or (b) alternating cycles of wetting and drying leading to the development of shrinkage cracks, permitting percolation of water that causes softening of the soil and acts as a driving force for instigating these slides. Considering the numerous miles of highway subgrades that have been successfully treated with lime (quick or hydrated) to reduce the swelling potential and increase the strength of troublesome clays,[1] the lime treatment of levees and levee slides should be a viable preventive and/or remedial treatment of these slides. The use of lime treatment for strength improvement is attractive in situations where geometry, right-of-way, water, or other obstacles prevent typical repair procedures of flattening the slopes or adding stabilizing berms.

Purpose

2. The objectives of this investigation were to (a) evaluate the feasibility of using lime to provide alternative design and remedial schemes for controlling slides and (b) furnish criteria concerning mix design, design parameters, and construction procedures.

Scope

3. Each District furnished soil from a levee slide within that District to be used in establishing mix design procedures and lime stabilization susceptibility of typical LMVD soils via laboratory tests. Other laboratory tests to determine effects due to compaction delay, density, and immersion were performed to provide recommendations concerning construction procedures. From these considerations, recommendations concerning mix design procedures and construction criteria are given.

PART II: BACKGROUND INFORMATION

Mechanisms of Lime Treatment of Soils

4. Since lime stabilization is the result of chemical reactions occurring with the soil, the following section is presented to provide background information concerning these reactions, an understanding of which will provide insight as to which soils are appropriate for treatment and construction considerations if lime is selected for treatment.

5. When lime is added to a lime-reactive soil, the dramatic changes of reduced plasticity and gradual increase in strength with time after compaction have generally been attributed to the following phenomena:[2,3]

a. Cation exchange: replacement of the exchangeable cations (sodium, Na^+; hydrogen, H^+; potassium, K^+; etc.) previously occupying the exchange sites of the soil by the calcium (Ca^{++}) cations derived from the lime.

b. Flocculation and agglomeration: an increase in grain size created by suppression of the double water layer surrounding the clay particles due to an increased electrolyte concentration, which results in flocculation.

c. Carbonation (of minor influence): reaction of lime and carbon dioxide from the atmosphere to form relatively weak cementing agents, calcium and/or magnesium carbonate.

d. Pozzolanic reactions: reactions between the silica and alumina present in the soil minerals, and the calcium from the lime to form new cementitious minerals.

Discussions concerning the importance of these four mechanisms must consider whether the soil is merely being modified or stabilized. In the case of modification, relatively small percentages of lime are incorporated within the soil with the primary effect of alteration of the physical properties. In the case of stabilization, sufficient lime to surpass modification is incorporated within the soil, and substantial strength gains as well as alteration of the physical properties occur.[4]

6. The mechanisms occurring as lime content is increased and mixed in a soil in the presence of moisture are envisioned as follows.[4] Initially, as small percentages of lime are added to cohesive soils,

the material becomes friable and attains a silty texture upon curing. These changes occur rapidly and may be attributed to one of two phenomena or a combination of both. The first phenomenon involves the cation exchange reactions, while the second involves compression of double layers of clay particles or "ion crowding" as it is sometimes called. These reactions occur as a result of increased hydrogen-ion concentration (pH) of the system and an increased concentration of Ca^{++} made possible by addition of lime.[3]

7. The result of these two phenomena is a reduction in plasticity of the treated cohesive soil. Although plasticity is usually indicated by the plasticity index (PI), a reduction in this value may not always be indicative of behavior. For instance, the liquid limit (LL) may be substantially increased by addition of lime, but a simultaneous increase in the plastic limit (PL) will be sufficient to cause a reduction in the PI. On the other hand, lime treatment may cause a reduction of the LL with very little effect on the PL, thus reducing the PI. Some conflicting opinions exist regarding effects of lime treatment on the LL of clays. This is to be expected since it has been found that the LL of the soil is more sensitive to cations present in clay than is the PL.

8. As lime content is gradually increased, plasticity of the clay is sharply reduced, and pH of the soil-lime mixture increases rapidly. The lime content at which the plasticity becomes zero and the pH approaches 12.4 has been termed the "lime fixation point" by some authors.[5] At this lime percentage, maximum compression of the ionic atmosphere and all cation-exchange reactions have occurred, since there is no further change in pH of the system and the soil has become supersaturated with Ca^{++}. Because this point or lime percentage represents maximum modification conditions, the term "modification optimum" has been applied to this lime percentage. Although small strength gains are obtained with lime contents below and at modification optimum, these gains are most probably related to aggregation of clay particles and increased angle of internal friction of the cohesive soil rather than formation of new minerals by pozzolanic reactions. Addition of lime percentages in excess of modification optimum provides free calcium

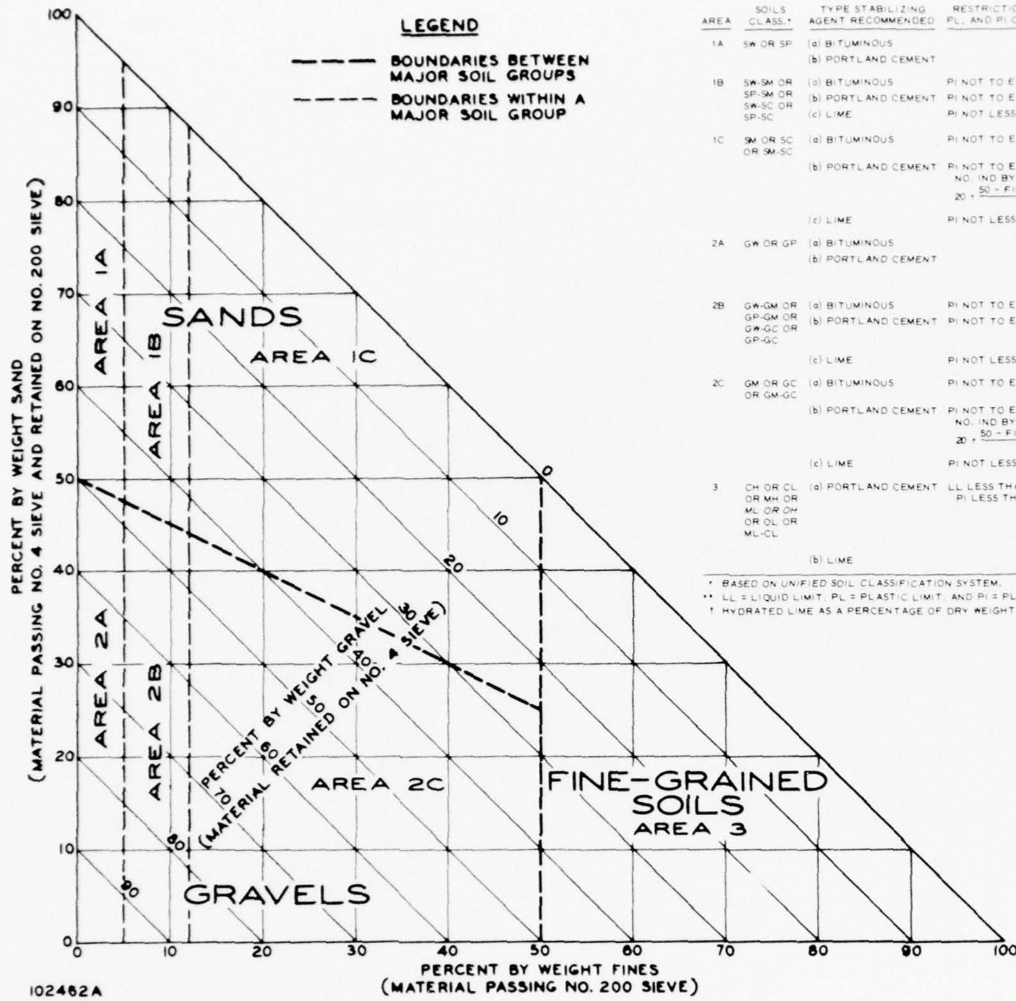
ions, which are available for pozzolanic reaction with silica and alumina to form new cementitious minerals.

9. These cementitious compounds fall into two classes: calcium silicate hydrates (CSH), and calcium aluminate hydrates (CAH). The high pH environment (12.4) created by the calcium hydroxide ($Ca(OH)_2$) leads to the increased solubility of the silica and/or alumina from the soil, thus furnishing the components for these reaction products. These pozzolanic reaction compounds formed at the contact points of the soil and lime create weak bonds between the soil particles. With time these reaction products become more crystalline, gaining strength and cementing the entire soil mass.

Soils Suitable for Lime Treatment

10. As discussed in the previous section, for lime stabilization to be effective, an available source of silica and/or alumina must be present for the formation of the cementitious pozzolanic reaction products. In this context, clayey soils respond best to lime treatments, where the clay's silica tetrahedral and alumina octahedral layers provide the sources of silica and alumina. Hence, clayey gravels, silty clays, and clays (i.e., GC, GC-GM, SC, SC-SM, CL, ML, CH, and MH soils) can generally be considered for stabilization with lime. Figure 1 presents the Corps of Engineers gradation triangle and criteria of a PI not less than 12 for soils responsive to lime stabilization,[6] as well as the approximate lime contents recommended by Ingles and Metcalf.[7]

11. In addition to plasticity and gradation, organic content, pH, clay mineralogy, and sulphates all affect the lime reactivity of a soil. Acid soils ($pH < 7$) are usually less responsive to lime treatments than soils with pH greater than 7. Thompson[2] reported that soils containing organic contents greater than 1 percent generally do not respond well to lime treatments. Hence, lime treatment of surface soils is not encouraged. The presence of sulfates may have a detrimental effect on lime stabilization due to the formation of ettringite (calcium sulfo-aluminate), which occupies a greater volume than the constituents from which it was



AREA	SOILS CLASS.*	TYPE STABILIZING AGENT RECOMMENDED	RESTRICTION ON LL, PL, AND PI OF SOILS**	RESTRICTION ON (-200 MATL)	REMARKS	APPROXIMATE LIME CONTENT† MODIFICATION	APPROXIMATE LIME CONTENT† STABILIZATION
1A	SW OR SP	(a) BITUMINOUS				NOT RECOMMENDED	NOT RECOMMENDED
		(b) PORTLAND CEMENT					
1B	SW-SM OR SP-SM OR SW-SC OR SP-SC	(a) BITUMINOUS	PI NOT TO EXCEED 10			NOT RECOMMENDED	~5%
		(b) PORTLAND CEMENT	PI NOT TO EXCEED 30				
		(c) LIME	PI NOT LESS THAN 12				
1C	SM OR SC OR SM-SC	(a) BITUMINOUS	PI NOT TO EXCEED 10	NOT TO EXCEED 30% BY WT		NOT RECOMMENDED	~5%
		(b) PORTLAND CEMENT	PI NOT TO EXCEED NO. IND BY EQ $20 + \frac{50 - \text{FINES CONT}}{4}$				
		(c) LIME	PI NOT LESS THAN 12				
2A	GW OR GP	(a) BITUMINOUS			WELL-GRADED MATL ONLY	NOT RECOMMENDED	NOT RECOMMENDED
		(b) PORTLAND CEMENT			MATL SHOULD CONTAIN AT LEAST 45% BY WT OF MATL PASSING NO. 4 SIEVE		
2B	GW-GM OR GP-GM OR GW-GC OR GP-GC	(a) BITUMINOUS	PI NOT TO EXCEED 10		WELL-GRADED MATL ONLY	2-4%	NOT RECOMMENDED
		(b) PORTLAND CEMENT	PI NOT TO EXCEED 30		MATL SHOULD CONTAIN AT LEAST 45% BY WT OF MATL PASSING NO. 4 SIEVE		
		(c) LIME	PI NOT LESS THAN 12				
2C	GM OR GC OR GM-GC	(a) BITUMINOUS	PI NOT TO EXCEED 10	NOT TO EXCEED 30% BY WT	WELL-GRADED MATL ONLY	2-4%	NOT RECOMMENDED
		(b) PORTLAND CEMENT	PI NOT TO EXCEED NO. IND BY EQ $20 + \frac{50 - \text{FINES CONT}}{4}$		MATL SHOULD CONTAIN AT LEAST 45% BY WT OF MATL PASSING NO. 4 SIEVE		
		(c) LIME	PI NOT LESS THAN 12				
3	CH OR CL OR MH OR ML OR OH OR OL OR ML-CL	(a) PORTLAND CEMENT	LL LESS THAN 40 AND PI LESS THAN 20		ORGANIC AND STRONGLY ACID SOILS FALLING WITHIN THIS AREA ARE NOT SUSCEPTIBLE OF STABILIZATION BY ORDINARY MEANS	1-3%	3-8%
		(b) LIME					

* BASED ON UNIFIED SOIL CLASSIFICATION SYSTEM.
** LL = LIQUID LIMIT, PL = PLASTIC LIMIT, AND PI = PLASTICITY INDEX.
† HYDRATED LIME AS A PERCENTAGE OF DRY WEIGHT SOIL.

Figure 1. Gradation triangle for aid in selecting a commercial stabilizing agent (from Reference 6)

formed. The expansion of this mineral disrupts bonding in the stabilized soil.

Mix Design Procedures for Soil-Lime Mixtures

12. Although most mix design procedures were developed for determining the stabilization susceptibility and optimum percentage of stabilizer required to treat soils for use in pavements, many aspects of these procedures are pertinent to using lime in levee slide repair. Of the myriad of mix design procedures,[8,9] the Air Force Soil Stabilization Index System (SSIS)[10,11,12] incorporates the best features and state of the art of several design procedures. The SSIS subsystem[11] for non-expedient subgrade stabilization with lime, which is the most applicable subsystem for levee slide treatment, is presented in Figure 2. The procedure consists of four steps in selecting the optimum lime content (OMC), specifically:

- a. Use pH test of Eades and Grim[13] to estimate approximate lime contents.
- b. Determine the lime reactivity (strength) via unconfined compression tests (UCT) of several soil-lime mixtures using Thompson's[14] criteria of a 50-psi* (3.6 tsf), $\Delta UCT > 50$ psi, strength increase to assess reactivity.
- c. Determine the durability via UCT after a 24-hr immersion, and apply Biswass'[15] criteria of an immersed strength of 30 psi (2.16 tsf).
- d. Select the optimum lime content (lowest percentage meeting these criterion).

Validations and/or modifications to improve this subsystem have been investigated by Dunlap[11] et al. and Currin, Allen, and Little.[12] Specifically, the improvements have centered on using accelerated curing procedures to estimate 28-day strengths. Originally, Thompson[14] recommended curing lime-treated specimens for 48 hr at 120°F to estimate 28-day strengths. However, based upon Biswass'[15] research, curing times and

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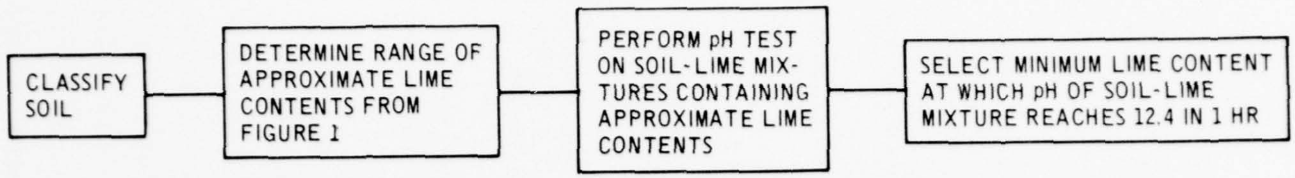
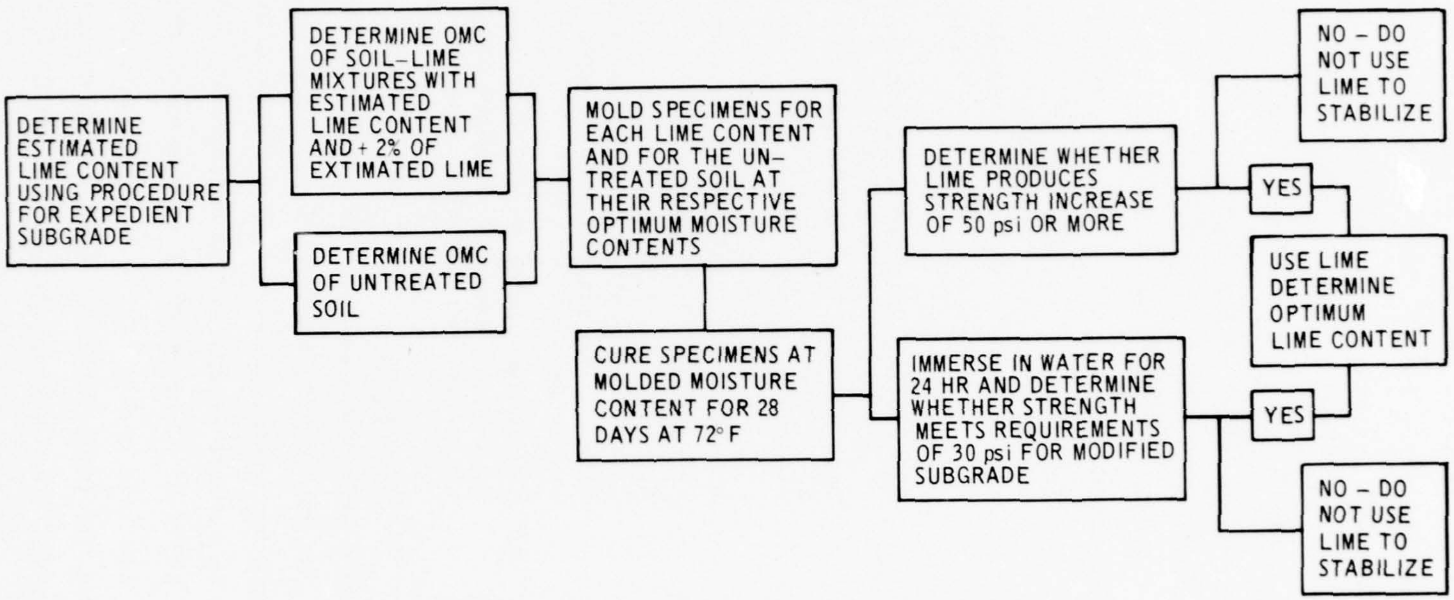
* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 5.



a. EXPEDIENT SUBGRADE STABILIZATION WITH LIME



b. NONEXPEDIENT SUBGRADE STABILIZATION WITH LIME

Figure 2. Subsystems for expedient and nonexpedient subgrade stabilization with lime (from Reference 11)

temperatures of 30 hr at 120°F or 65 hr at 105°F have been adopted by Dunlap et al. for expedient base course stabilization with lime. Biswass also found that after curing, lime-treated soils with UCT strengths greater than 100 psi would meet the reactiveness criteria of a 50-psi strength increase ($\Delta UCT > 50$ psi). Hence, UCT strengths of untreated soil would not be required to verify a $\Delta UCT > 50$ psi. Accordingly, the subsystem for expedient base course stabilization adopted by Dunlap et al. included these criteria.

13. Currin, Allen, and Little[12] validated various aspects of the SSIS as diagrammed in Figure 3. Their results verified that:

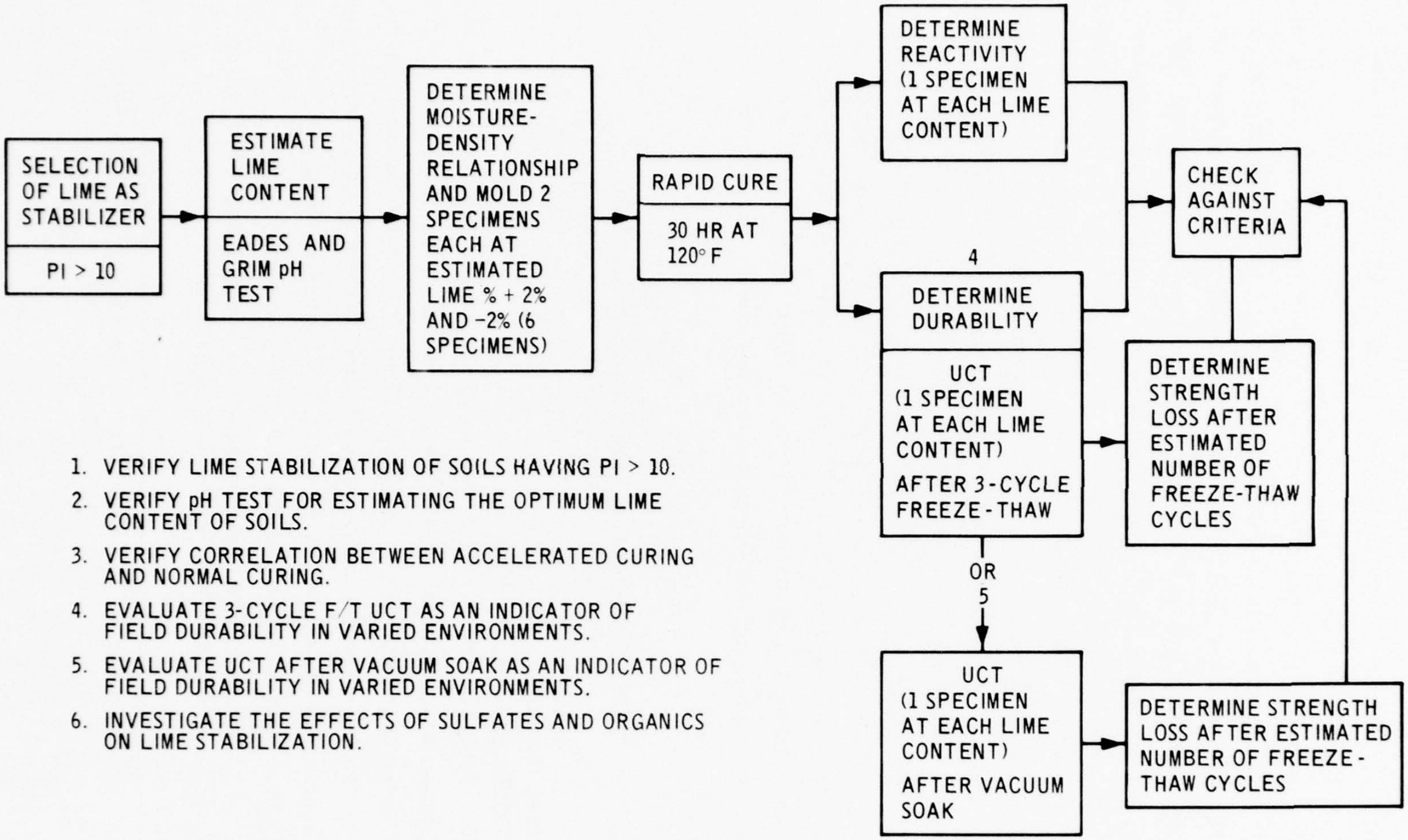
a. The minimum PI criterion of 10 appears to be adequate to ensure pozzolanic potential of the soil when mixed with lime, in that unconfined compressive strength increases of 50 psi after 28 days of curing were obtained for the soils tested.

b. The pH test is acceptable for determination of an initial lime content of 19 soils tested; the pH test predicted the optimum lime content strengthwise within 1 percent for 16 of the soils and within 2 percent for the remaining 3. However, caution is urged when applying the pH test to soils with high organic contents. Thompson and Eades[16] also observed that the pH test is accurate except for some highly weathered tropical soils.

c. Although the data varied over a wide range, statistically 30-hr curing at 120°F is a valid substitute for normal 72°F curing and can thus be used to estimate 28-day strengths.

d. Vacuum saturation is the most expedient method for evaluating immersed strength and can be used to estimate three-cycle freeze-thaw data.

14. In dissention, Townsend and Donaghe[8] and Drake and Haliburton[17] have shown that use of accelerated curing temperatures of 120°F can create abnormally high strengths and that 105°F is a more appropriate temperature. It was also found[8] that the number of hours required to achieve 28-day normal curing strength varies widely from the 65 hr at 105°F or 30 hr at 120°F (recommended criteria) and that these criteria can incorrectly assess lime reactiveness of a soil (Table 1). To improve the inaccuracies of accelerated curing time recommended by Dunlap et al.[11] and Currin, Allen, and Little[12] for the SSIS, Townsend



1. VERIFY LIME STABILIZATION OF SOILS HAVING PI > 10.
2. VERIFY pH TEST FOR ESTIMATING THE OPTIMUM LIME CONTENT OF SOILS.
3. VERIFY CORRELATION BETWEEN ACCELERATED CURING AND NORMAL CURING.
4. EVALUATE 3-CYCLE F/T UCT AS AN INDICATOR OF FIELD DURABILITY IN VARIED ENVIRONMENTS.
5. EVALUATE UCT AFTER VACUUM SOAK AS AN INDICATOR OF FIELD DURABILITY IN VARIED ENVIRONMENTS.
6. INVESTIGATE THE EFFECTS OF SULFATES AND ORGANICS ON LIME STABILIZATION.

Figure 3. Hypothesized design procedure for expedient and nonexpedient lime stabilization (after Reference 12)

and Donaghe derived a system using 7-day normal cured strengths and 105°F accelerated curing.

15. Durability criteria for soil-lime mixtures are primarily to assess freeze-thaw resistance beneath pavements. While freeze-thaw durability may not be a problem in most of the LMVD, an assessment of immersion durability would be prudent considering hypothetically that a lime-treated, restored levee slide may have to function beneath water during high river stages. Biswass[15] correlated a 24-hr short-term immersion test after 28-day normal curing with long-term immersion (21 days) after 7-day normal curing. For subgrade materials he recommended a 30-psi residual strength as acceptable. Dunlap et al.[11] adopted these criteria for the SSIS. If extensive freeze-thaw conditions are anticipated, deterioration of soil-lime mixture may occur and should be considered. A UCT-strength of 20 psi after three freeze-thaw cycles has been recommended as acceptable.[11,12] In the case of levee slide restoration, experience indicates that a 28-day UCT-strength of 9.0-10.5 tsf (125-150 psi) should provide adequate freeze-thaw resistance for this application.

Previous Lime Stabilization of Levee Slides and Canal Slopes

Joiner-West Memphis Levee System, Memphis District

16. Probably the most extensive repair of levee slides using lime stabilization was conducted by the Memphis District on the Joiner-West Memphis Levee System on the Mississippi River during the summer and fall of 1974. The total project consisted of lime treatment of 18 river-side slides consisting of 42,662 cu yd with 5 percent lime at a cost of $390,763.89. The construction sequence consisted of:*

- a Stripping and stockpiling the topsoil for landscaping after completion of slide repair.

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* Personal communication, K. Akers and R. Prislovsky, CE, Memphis District.

_b_. Positioning a dragline on the slide surface to remove material from the head of the slide. The backslope never exceeded 1-1/2:1, and drainage was maintained away from the side scarp.

_c_. Removing material from the slide toe by scraper.

_d_. Transporting the slide material to mixing pads where 5 percent lime from bulk trucks was spread on 8-in. lifts, wetted down, and mixed by disking.

_e_. Lime treating the exposed slide surface after removal of the failed material and disking the bottom and sides where possible.

_f_. Replacing the lime-treated material in 8-in. lifts to a 3:1 slope and semicompacting by four to six passes of a crawler tractor.

_g_. Replacing 4-6 in. of topsoil, fertilizing, and seeding.

An inspection of the treated slides a year and a half later showed that the treated areas were in excellent condition, except for minor patches of topsoil erosion. The surface of the treated slides was extremely hard with some surface cracks, but no erosion of the treated material was evident. Except for increasing the thickness of topsoil to 8-12 in. instead of 4-6 in., these experiences indicate that excellent results may be expected. The following tabulation provided by the Memphis District summarizes the effects of lime content on material from this project, and Appendix A presents specifications for the project. These data indicate that an 8 percent lime treatment would give a lower PI and higher strength than the 5 percent lime that was used.

Summary of Memphis District Data from Elaine, Arkansas

Lime Content % (Based on Dry Weight of Soil)	LL	PL	PI	UCT Strength psf	Dry Density pcf
0	85	22	63	--	--
3	76	29	47	2400	112
4	69	30	39	2300	111
5	68	33	35	2600	111
7	63	36	27	2600	110
8	66	37	29	2800	109

DeGonia, Grand Tower, Fountain Bluff, and Prairie du Rocher Levee Systems, St. Louis District*

17. Lime stabilization of 12 river-side levee slides has been conducted by the St. Louis District along the DeGonia, Grand Tower, Fountain Bluff, and Prairie du Rocher Levee Systems during the summer of 1976. Typically the slides were less than 100 ft long in levees 20-25 years old. Since the slides were small, repair was accomplished using limited small equipment (mainly tractor and front-end loader). The repair sequence was: (a) excavate the failed material, (b) spread in 8-in. lifts in the adjacent berm, (c) add 5 percent hydrated lime from bags, (d) disk with a tractor-pulled disk, (e) after complete excavation of the slide material, lime and disk the exposed slide surfaces, (f) replace the lime-treated material and semicompact to the original 3:1 or 4:1 slope, and (g) replace 1 ft of topsoil. The slide material was extremely wet, and the lime actually dried and improved the workability of the soil; hence, no water was added during the mixing phase. Since the slides were small (<100 ft in length) problems were encountered in distributing the lime. It was deemed that to have a bulk spreader truck on the site full time would involve too much dead time and the resulting expense, hence several methods of spreading were tried. Initially, a 4-ton-capacity fertilizer spreader was used, but it was unsatisfactory as too many passes were required to achieve the addition of 5 percent lime. Spreading was finally accomplished by emptying 50-lb sacks of lime into a front-end loader bucket and then distributing it from this bucket. Although 65 tons of lime per slide corresponded to the suggested design percentage, generally only 30-35 tons per slide were used. It was found that mixing lime to the 8-in. lifts as they were excavated was a good construction technique. Cost estimates indicate that conventional slide repair with an inclined sand blanket used to provide internal drainage, as was done on 15 landside slides in the same area concurrently, was approximately $1500 per slide versus $3500 per

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* Personal communication, C. Martin, CE, St. Louis District.

slide for the riverside lime-treated slides. However, Mr. C. Martin,* resident engineer, who had previously repaired over 50 slides in this area, felt that the extra expense of lime was justified and that a much better repair was achieved. These remarks are most encouraging as the St. Louis District has demonstrated that even with routine construction equipment, a flexible mix design (35 tons instead of 65 tons), innovative spreading techniques, and delays of several days between mixing and compaction, a highly stable repair can be achieved. Today, the repaired slide surfaces are extremely hard with no signs of washing or erosion.

Friant-Kern Canal,
Bureau of Reclamation[19]

18. Since construction in the late 1940's the Friant-Kern Canal in California has experienced cracking, sliding, and sloughing on the side slopes in areas of expansive clays and in both the concrete-lined and earth-lined portions. Failure was generally attributed to the highly expansive fat clay (CH) soils, forming deep surface cracks by shrinkage that result in a loss in shear strength, or swelling and softening as they become saturated that also result in lower shear strengths. In the early 1970's, after having unsuccessfully converted failed concrete linings to earth sections with flatter slopes or trying electrochemical treatment, the Bureau of Reclamation decided to remove portions of the canal lining, flatten the slopes, and reline the canal using a compacted soil-lime mixture. Rehabilitation shown in the upper diagram of Figure 4 for the earth-lined sections consisted of flattening the slopes from 1.5:1 to 2:1. The compacted soil-lime earth lining was to be 2 ft thick for access roads on the tops of both banks and for the canal bottom, while the side slopes were 3.6 ft thick normal to the slope. In the case of the sections beneath a concrete lining, the side slopes were left at 1.5:1, resulting in a thickness of 4.4 ft normal to the slope, with the bottom and access road sections being 2 ft thick.

19. Construction of the access roads along the canal banks and the canal bottom consisted of:

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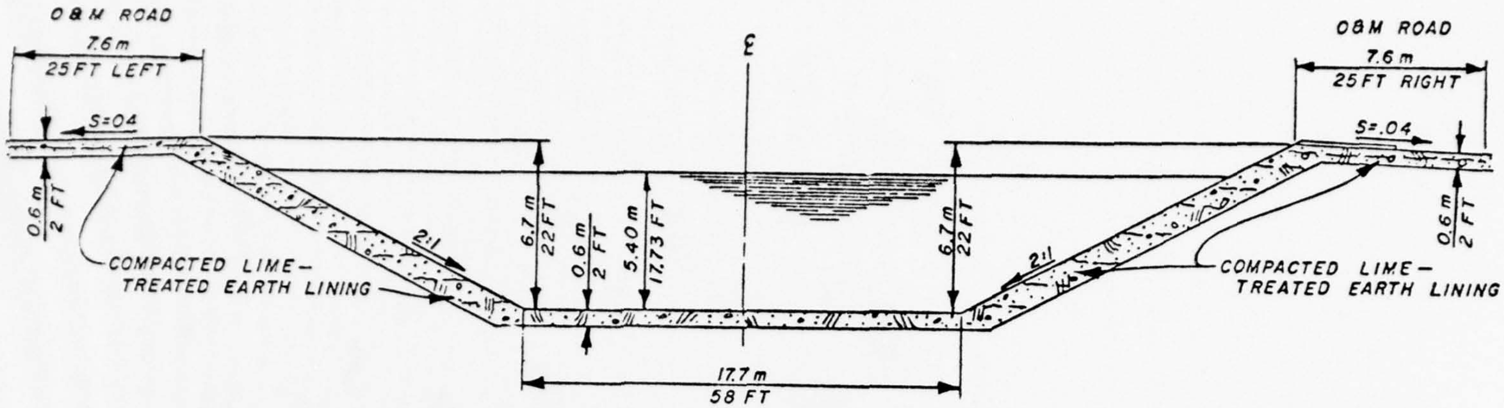
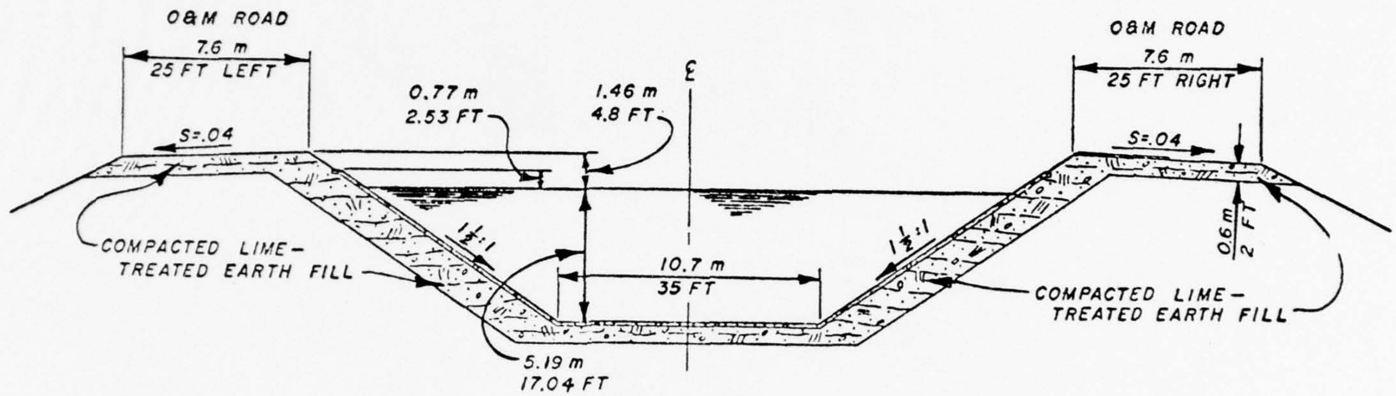
* Martin, op. cit.



TYPICAL EARTH REHABILITATION SECTION



TYPICAL CONCRETE LINED REHABILITATION SECTION

Figure 4. Rehabilitated canal sections (from Reference 19)

a. Removing the top half of material to be treated (1 ft) and stockpiling.

b. Lime treating the bottom half (1 ft) by ripping, adding 4 percent quicklime and water, mixing, allowing the mixture to mellow, and then recompacting with a vibratory sheepsfoot roller.

c. Moving the top lift back (1 ft), spreading, treating, with 4 percent quicklime, watering, mixing, allowing to mellow, and recompacting.

Construction of the canal side slopes followed this sequence:

a. All the material to be stabilized was removed by cutting long, sloping benches or ramps from the top of the canal bank to the bottom, with the cut extending far enough into the slope to remove the required material.

b. Two percent of quicklime was spread over the top 1 ft of the bench surface, which was mixed with 2 percent quicklime and pushed into the canal bottom.

c. The material was then spread on the canal bottom in 1-ft lifts and 2 percent additional quicklime added.

d. Water was added to at least 2 percent over optimum water content and mixed by dozers and graders.

e. After about 6.5 ft of material had been mixed and cured for 24 hr, bulldozers spread the material in 1.2-ft lifts on the slopes, which were then compacted by winching a self-cleaning sheepsfoot roller up and down the slope until a specified compacted depth of 3.6 ft was achieved.

20. Even though construction took place during December and January of 1972-1973 and 1973-1974 when the canal was dry, excellent results were obtained. In fact, the earth-lined sections performed so well during watering that concrete linings were deemed superfluous and were discontinued. Current (1976) conditions indicate a slight fluff (1 to 2 in.) has formed on treated surfaces due to wetting and drying, but underlying material is quite hard and resistant.*

* Personal communication, A. K. Howard, Bureau of Reclamation.

PART III: MATERIALS AND TESTING PROCEDURES

Materials

21. Each District in the LMVD furnished material from a typical levee slide within that District for testing. Specifically, the locations and corresponding Districts were:

a. DeGonia Levee System, St. Louis District. No information is available concerning site.

b. Little River Levee System, Memphis District. Figure 5 shows a landslide on the Little River Levee System near

Figure 5. Slide on Little River Levee System, Memphis District

Nash, Missouri, and Figure 6 presents a schematic of the conditions. The levee is approximately 25 ft high in this section, with adjacent unfailed slopes of 1:3.5-4.0. The slide extends approximately from sta 24+94 to 26+83 or 190 ft. The close proximity of the railroad at the slide toe precludes repair by flattening the slope or placement of stabilizing berms, unless the railroad is relocated. In this case, either a retaining wall or improvement of the soil strength by admixtures, which would

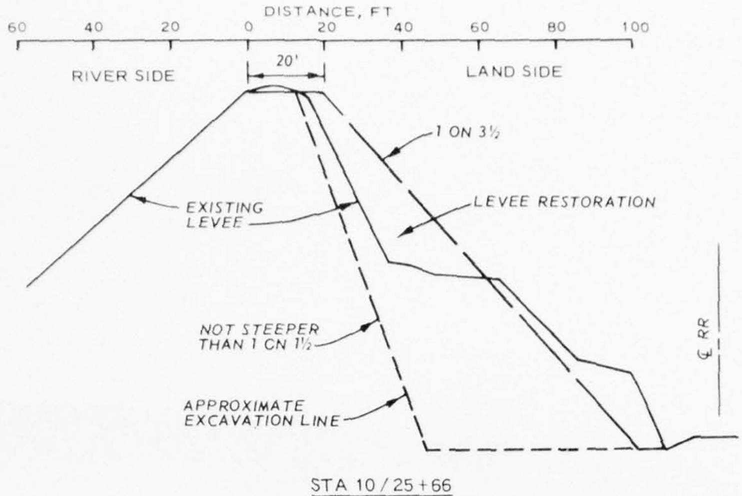


Figure 6. Profile of slide conditions, Little River Levee System, Memphis District

permit repair to prefailure slopes or steeper, would be a viable restoration method. The material sampled was from the base of scarp, which is thought to represent material from or near the failure plane.

c. Roundaway Bayou Levee, Vicksburg District. Figure 7 presents a river-side slide on the Roundaway Bayou Levee near Vicksburg, Mississippi, while Figure 8 presents the geometry of the conditions. The levee is approximately 25 ft high in this section, with prefailure slopes of 1:3.5-4.0. The slide extends approximately from sta 4161+95 to 4164+14 or 219 ft. The material sampled was from the base of the scarp.

d. Wallace Lake Dam, New Orleans District. Figure 9 shows a slide on the upstream face of Wallace Lake Dam. This slide occurred in an area that had failed when the slopes were 1:3 and had been improperly restored 3 months earlier to 1:4 slopes, prior to the second slide that was due to improper reconstruction as shown in the figure. Figure 10 is a schematic of the geometry of the slide. The levee section is approximately 20 ft high in this section. The slide is approximately 250 ft long. The material used in the testing program was a composite of undisturbed samples from four borings taken from the slide area.

22. An examination of these slides reveals that they occurred in levees over 20 years old in sections approximately 20 to 30 ft high.

Figure 7. Slide on Roundaway Bayou Levee, Vicksburg District

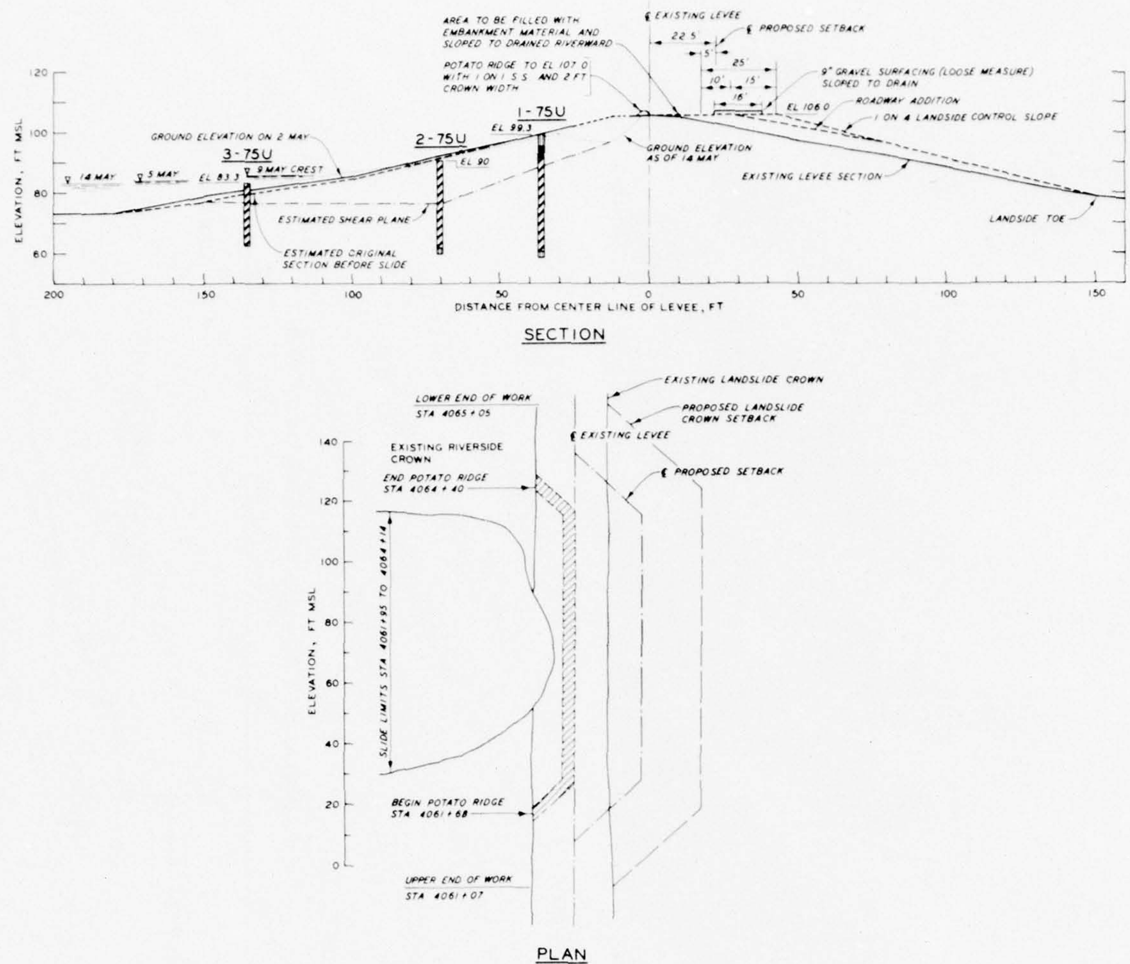


Figure 8. A schematic of slide conditions, Roundaway Bayou Levee, Vicksburg District

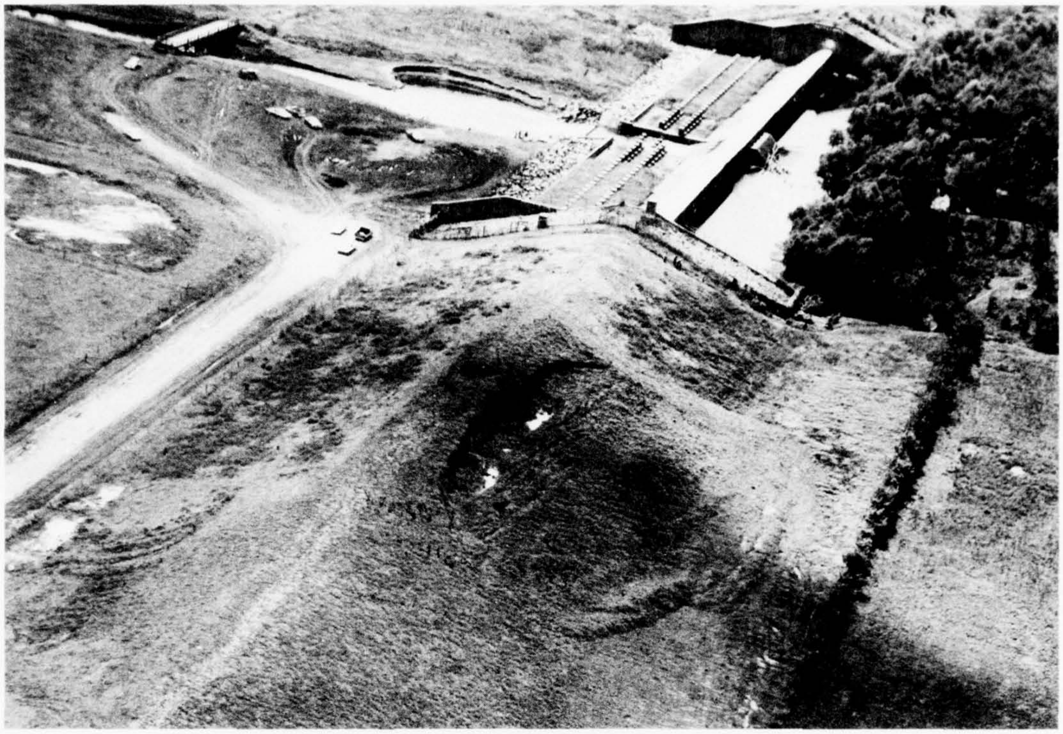


Figure 9. Slide on Wallace Lake Dam, New Orleans District

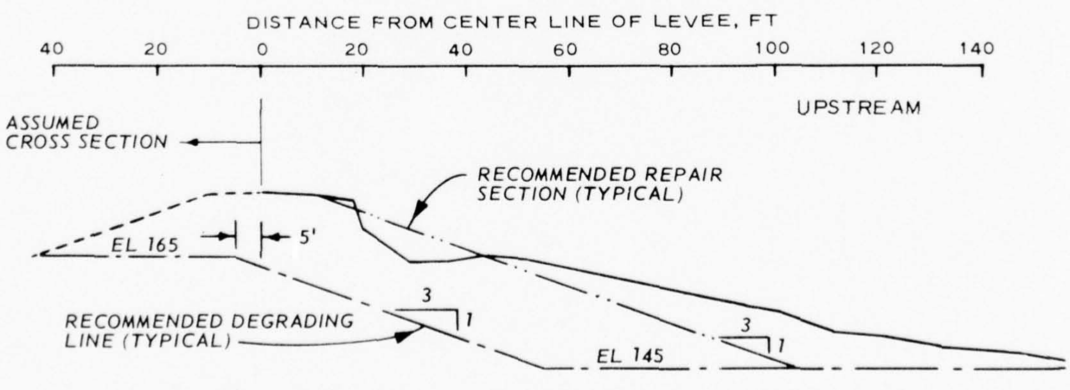


Figure 10. A schematic of slide conditions, Wallace Lake Dam, New Orleans District, at sta 38+50

Slopes were 1:3 and 1:4, and material was always a CH soil at a high water content. Typically, the slides were small (100-300 ft in length), varying in depth from 2 to 15 ft. Failure was attributed to continued seasonal wetting and drying, which created numerous cracks and fissures and resulted in a blocky structure. Movement of water into these fissures softens the material along these planes causing a decrease in strength and failure.*

23. The physical properties presented in Figures 11-14 classify these soils as CH, the order of decreasing plasticity being Little River, Roundaway Bayou, DeGonia Levee Systems, and Wallace Lake Dam.

24. The lime used was a type N, normal hydrated, high calcium, commercial grade lime, $G_s \approx 2.47$, manufactured by Pelican State Lime Company, Morgan City, Louisiana.

25. A waste lime by-product, Code L, which is generated in the kilns during lime production, was investigated on a minor basis. Because Code L is a waste product, the price, free on board (FOB) at the Mississippi Lime Company, St. Genevieve, Missouri, is $1.50 per ton compared with $28 per ton for hydrated lime, or $24.25 per ton for granulated quicklime.

Testing Procedures

26. Based upon the literature review information, the SSIS[10] mix design procedure was selected as the basis for evaluating the lime stabilization susceptibility of these soils. Tests were conducted to provide information on accelerated curing effects, water content-density effects, compaction delay, and immersion. The testing program consisted of pH tests, Atterberg limits, compaction characteristics, and UCT's on 2.0-in.-diam by 4.0-in.-high lime-treated specimens cured at various times and temperatures. Figure 15 presents a flow diagram of the testing program.

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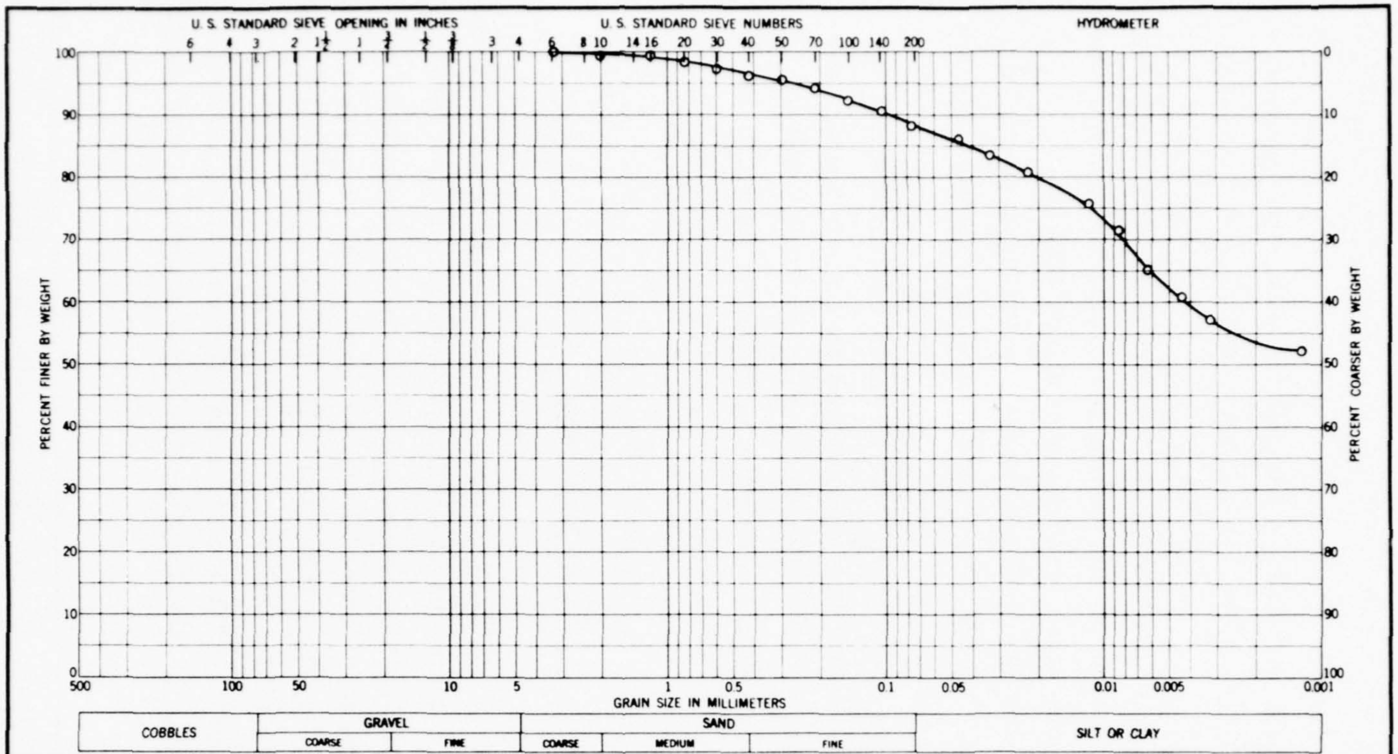
* Personal communications: L. Cooley, CE, Vicksburg District; and G. Postol, CE, St. Louis District.



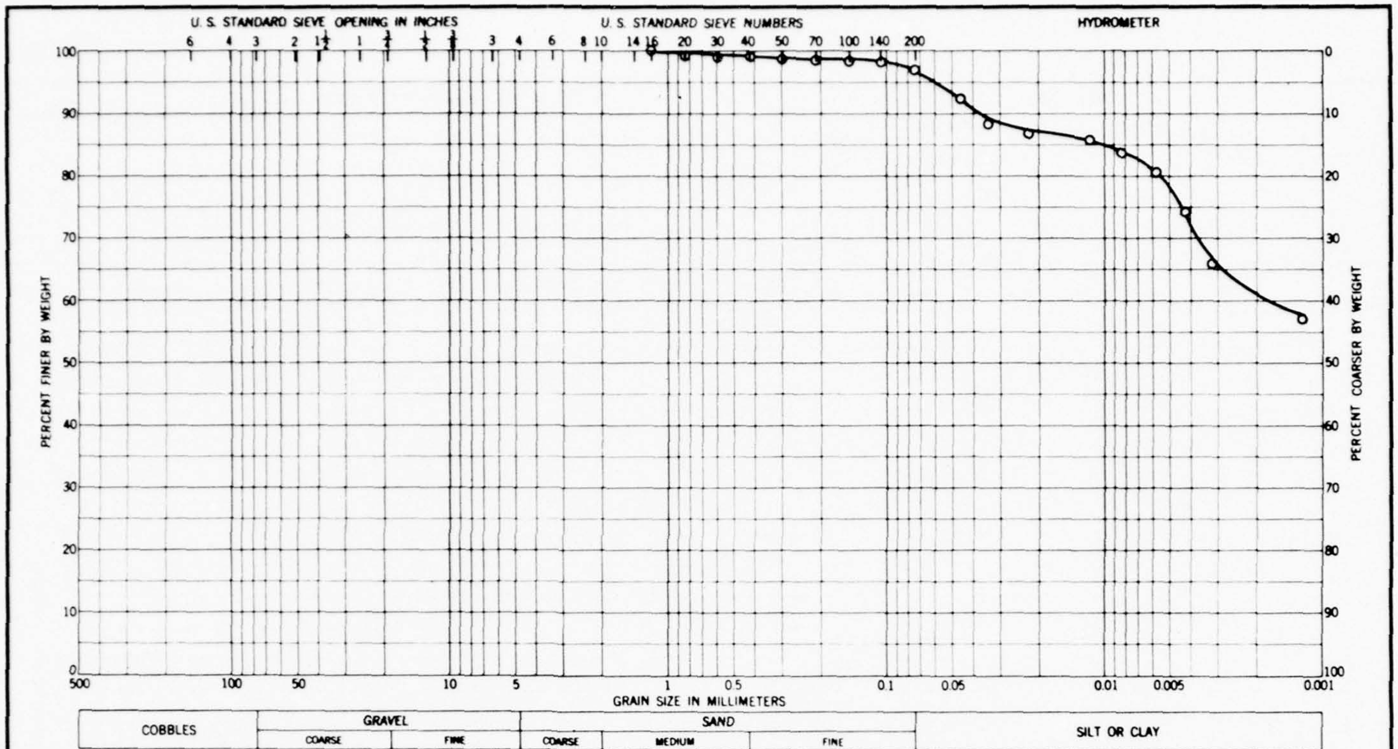
Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		PLASTIC CLAY (CH)		65	20	45
		WITH SAND				
		Gs = 2.71				

Project	USE OF LIME IN EMBANKMENTS
Area	
Boring No.	DAGONIA
Date	17 MAY 1976

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 11. Physical properties of soils, DeGonia Levee System



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		PLASTIC CLAY (CH)		94	30	64
		BROWN				
		Gs = 2.76				

Project USE OF LIME IN EMBANKMENTS

Area

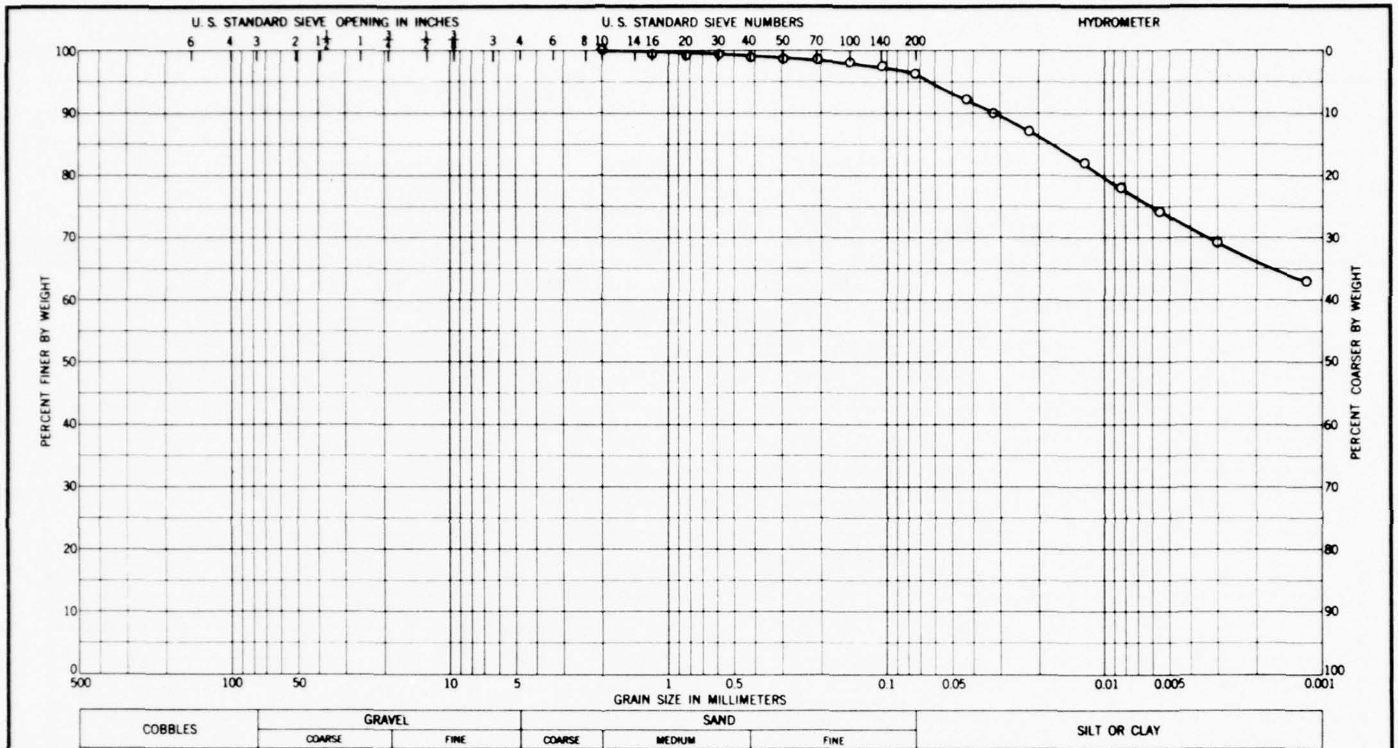
Boring No. LITTLE RIVER

Date 17 MAY 1976

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 12. Physical properties of soils, Little River Levee System



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		PLASTIC CLAY (CH)		82	27	55
		BROWN				
		Gs = 2.76				

Project USE OF LIME IN EMBANKMENTS

Area

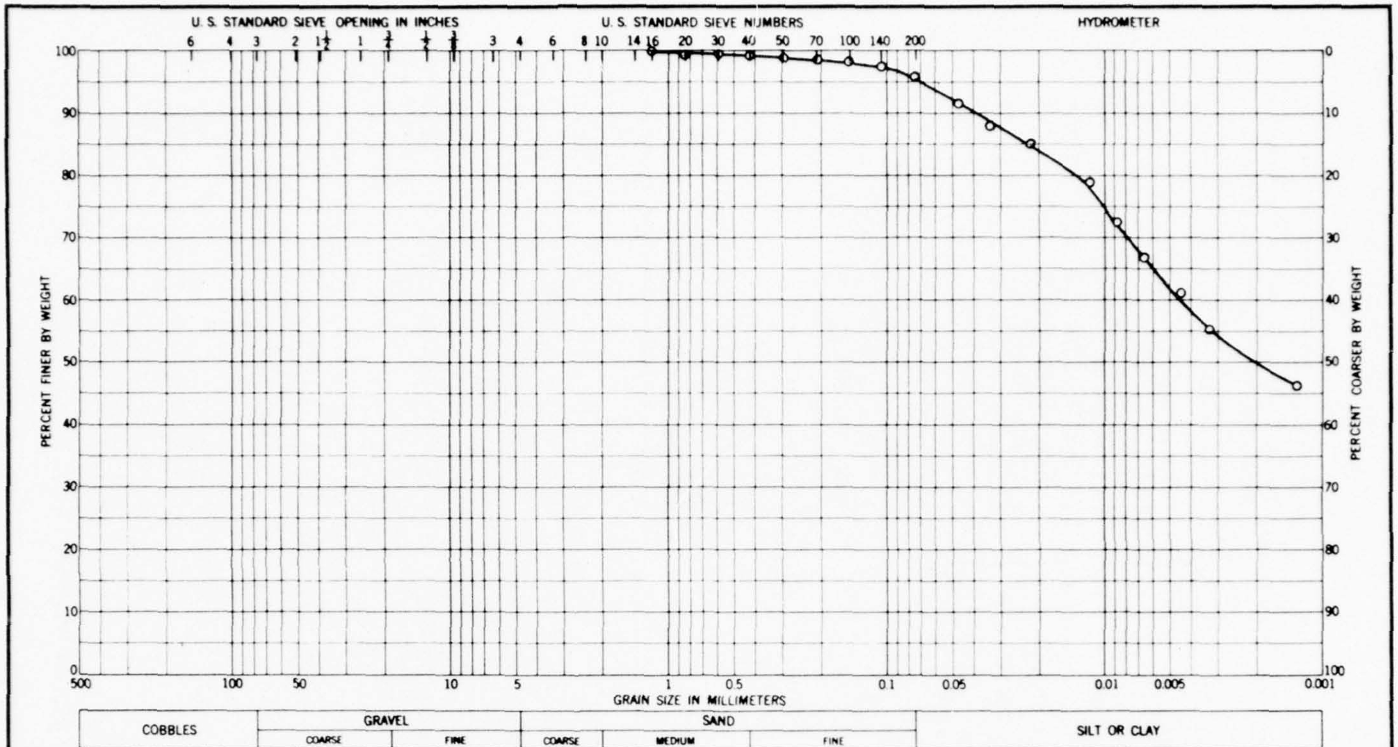
Boring No. ROUNDAWAY BAYOU SLIDE

Date 17 MAY 1976

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 13. Physical properties of soils, Roundaway Bayou Levee



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		PLASTIC CLAY (CH)		63	20	43
		BROWN				
		Gs = 2.76				

Project: USE OF LIME IN EMBANKMENTS

Area:

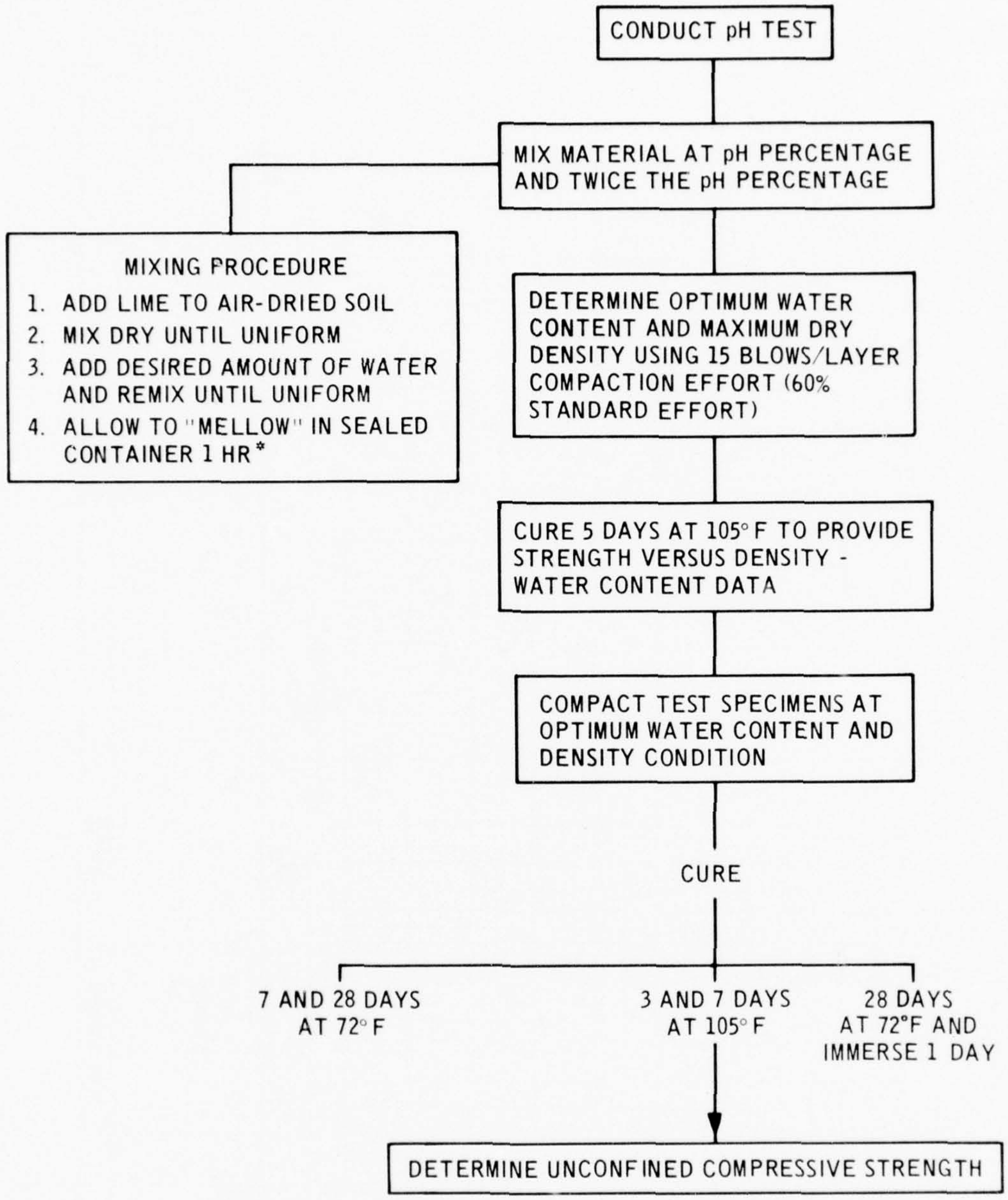
Boring No. WALLACE LAKE COMPOSITE

Date: 17 MAY 1976

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 14. Physical properties of soils, Wallace Lake Dam



* COMPACTION DELAY TEST: ALLOW TO "MELLOW" 8, 24, OR 72 HR PRIOR TO COMPACTION.

Figure 15. Flow diagram of the laboratory testing program

Selection of lime content

27. The effect of lime content on stabilization response was evaluated by using two lime contents. The lime modification percentage was estimated by the pH test (Appendix C), while twice the pH percentage was arbitrarily selected as a second lime content. The pH of the various soil-lime slurries was measured using a Beckman Zeromatic II pH meter calibrated with a standard buffer solution.

Mixing procedure

28. The soil and lime were dry-mixed by hand until a homogeneous mixture was observed. The desired amount of water was then added and thoroughly mixed by hand. The moist mixture was next placed in a sealed plastic container and usually allowed to mellow 1 hr prior to compaction unless compaction delay was investigated, then mellowing was 8, 24, or 72 hr. Only 2000-g batches were mixed to prevent times greater than 1 hr between mellowing and compaction of the specimen.

Compaction of specimens

29. Specimens 2 in. in diameter by 4 in. high were compacted in three layers inside a Vicksburg miniature mold. To simulate field semi-compaction, a reduced compaction effort of 13 blows total (first two layers, 4 blows each; third layer, 5 blows) of a 4-lb rammer falling 12 in. was used. This effort represents 58 percent of standard compaction effort, which is equivalent to the 15-blow compaction effort described in EM 1110-2-1906.[20] Immediately after compaction, the specimen was extruded and weighed to the nearest 0.01 g.

Curing

30. Immediately after compaction and weighing, the specimen was placed on a rack over 1 to 2 in. of water inside a plastic container to prevent loss of moisture during curing. The 105°F cured specimens were placed in an incubator and cured 3, 5, or 7 days, while the 72°F cured specimens were placed in a moist room and cured 7 or 28 days. For immersion tests after 28 days curing, the specimens were immersed for 24 hr, removed from the water, and allowed to stand 1 hr prior to testing.

Strength testing

31. After curing the designated length of time, the specimens were removed from their curing chambers, weighed to determine if any moisture loss or gain had occurred, and measured to note any change in dimensions. Unconfined compression strengths were determined for specimens loaded at a strain rate of 1 percent per minute using a load cell calibrated to the nearest 0.1 lb, and an LVDT was calibrated to the nearest 0.001 in. Both load and deformation were recorded digitally on a Doric Digitrend model 210 or x-y recorder. After testing, the moisture contents of the specimens were determined.

PART IV: PRESENTATION AND DISCUSSION OF TEST RESULTS

pH Test

32. The results of the pH tests on the four soils tested are summarized in the tabulation below and shown graphically in Figure 16:

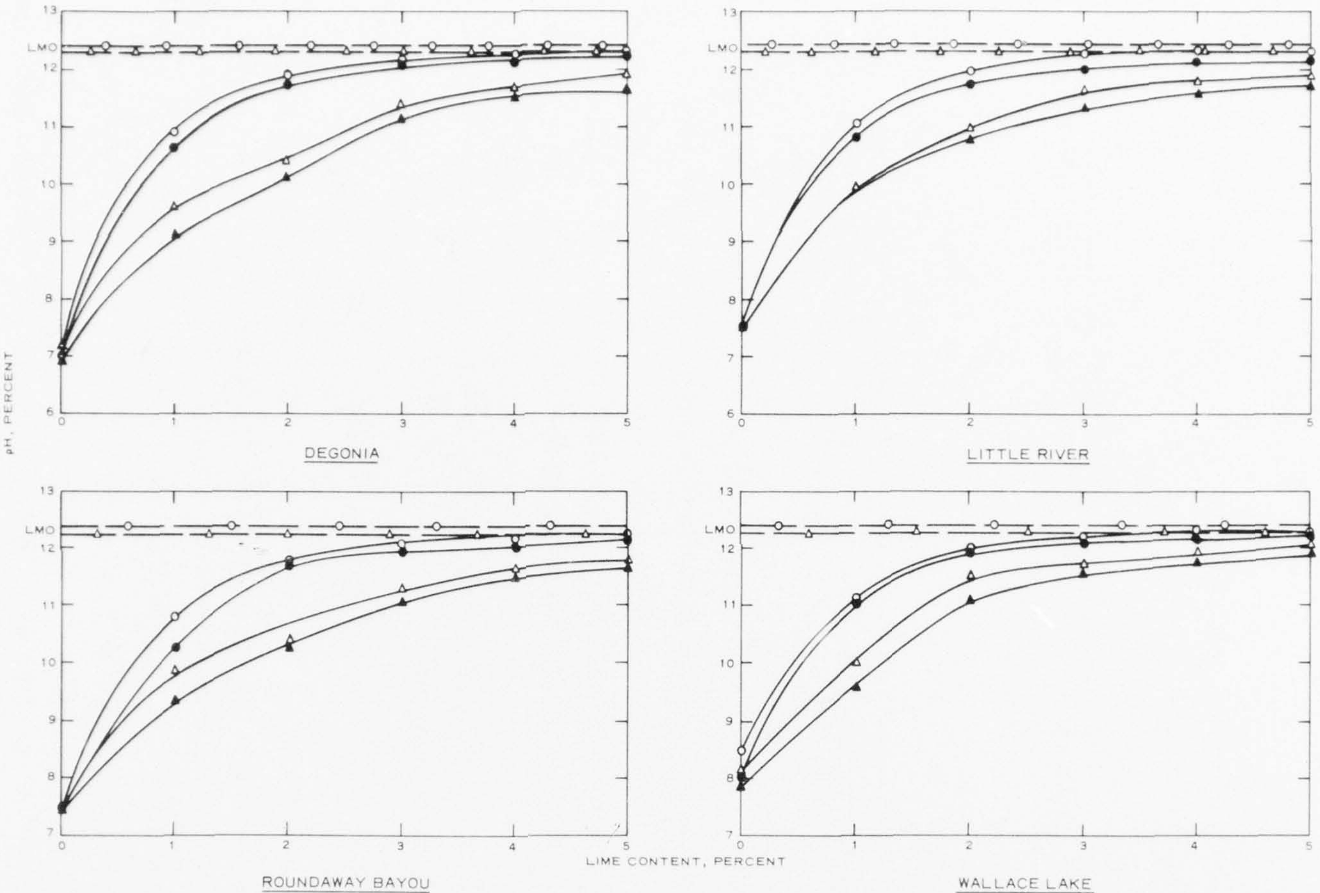
Soil	pH Percentage	
	Hydrated Lime	Code L Lime (Estimated)*
DeGonia	4	8
Little River	4	8
Roundaway Bayou	5	8
Wallace Lake	4	8

* Estimated by extrapolation of pH versus lime content curves.

Coincidentally, the pH percentage of all these soils is about 4 percent. Based on these results, lime contents of 4 and 8 percent were selected for treating the soils. These results suggest that about twice as much Code L lime is required to achieve modification optimum as hydrated lime. The results presented in Figure 16 show that slurries of both the Pelican hydrated and Code L limes had a pH of approximately 12.3. Unfortunately, the maximum lime content tested was 5 percent, which was insufficient to achieve a pH of 12.3 for the Code L lime; hence, this pH percentage was estimated by extrapolation.

Atterberg Limits

33. The effects of the pH and twice the pH lime content on plasticity of these soils are summarized in Figure 17. The data show that, except for the Roundaway Bayou material, the pH percentage, 4 percent, was sufficient to achieve the maximum possible reduction in PI, and additional lime, 8 percent, produced no significant further reduction in plasticity. Hence, the pH test accurately estimates the modification optimum. In no case did the lime-treated soils become nonplastic. The mechanism for plasticity reduction was a large increase in PL coupled with a smaller decrease in LL. Similar results in agreement between



NOTE: OPEN SYMBOLS REPRESENT pH VALUES AFTER 1 HR.
SOLID SYMBOLS REPRESENT pH VALUES AFTER 24 HR.
LMO REPRESENTS LIME MODIFICATION OPTIMUM, pH OF LIME SLURRY.

LEGEND

O PELICAN
Δ CODE L

Figure 16. Results of pH tests

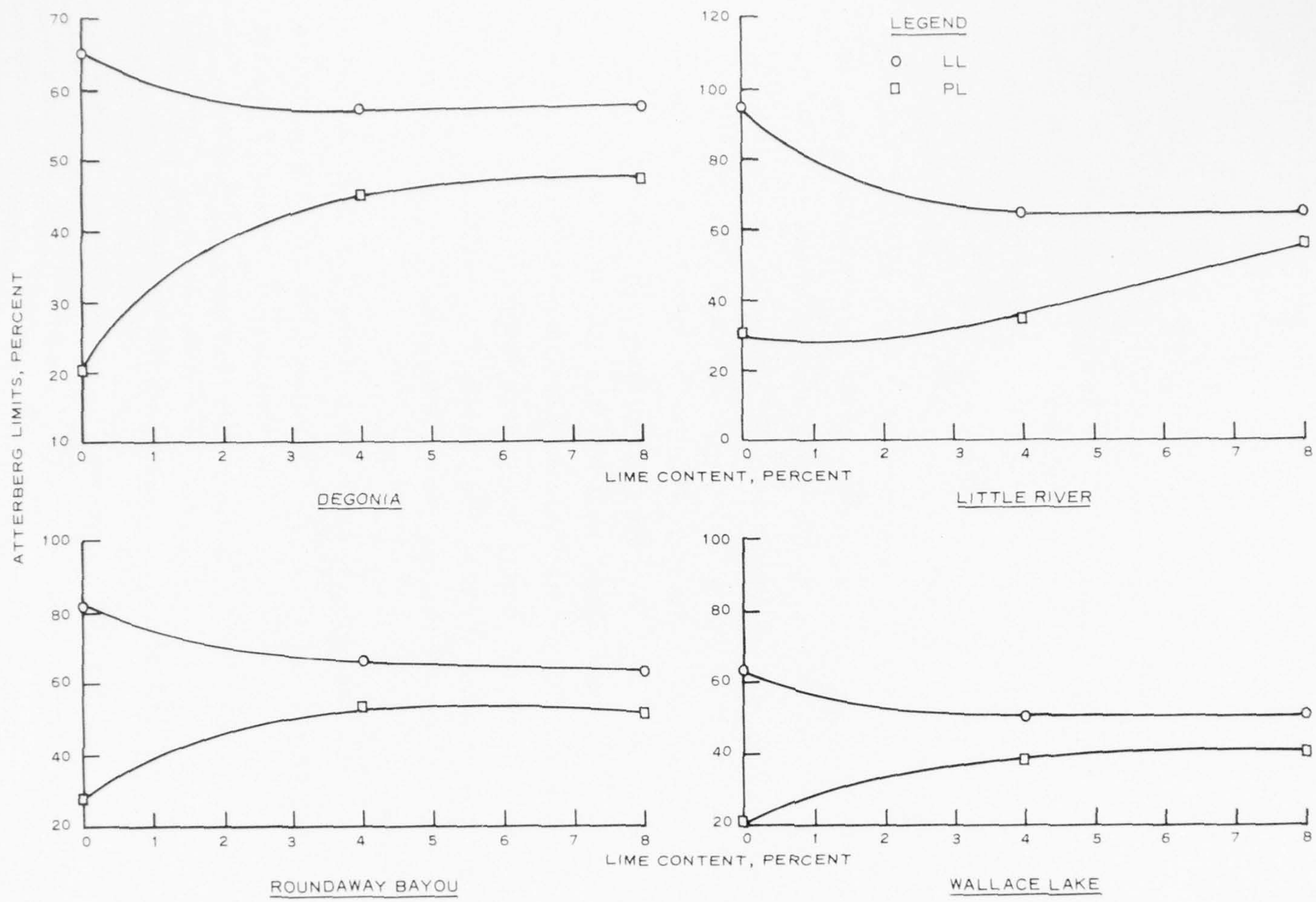


Figure 17. Effect of lime content on plasticity of levee slide soils

these limits and pH test as well as mechanism for plasticity reduction have been reported by Biswass.[15] Since the simpler pH test accurately estimates the modification optimum, its usage is recommended.

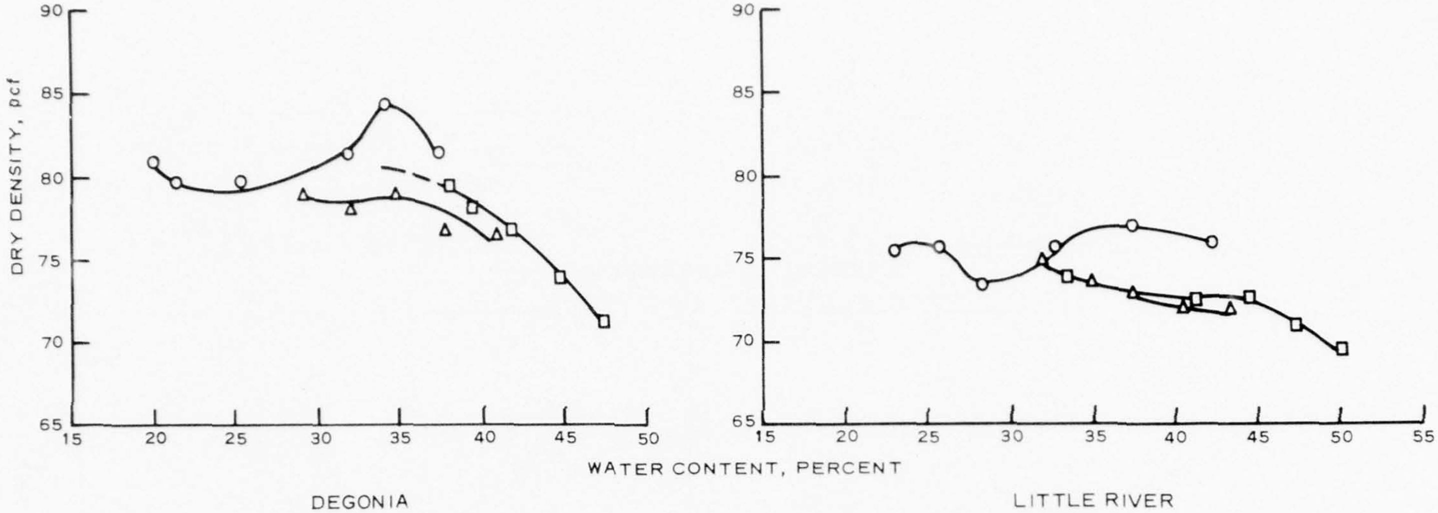
Compaction of Soil-Lime Mixtures

34. The dry density-water content relationships for the four soils plus 4 and 8 percent lime are summarized in Figures 18 and 19. These results show that, in the case of highly plastic clays, particularly Little River and Roundaway Bayou, at these low compaction efforts, water content has only a slight effect on the maximum dry unit weight (or dry density). Consequently, selection of the optimum water content and maximum dry density for these two soils was difficult. Slightly more peaked water content-dry density curves were obtained, and selection of optimum conditions was more accurate for DeGonia and Wallace Lake soils. Based upon these results, the compaction water contents indicated in Figures 18 and 19 were selected for preparing test specimens. As expected, the addition of lime to these soils caused a decrease in maximum dry unit weight and a slight increase in optimum water content.[9] These changes ranged from a 1.4- to 6.3-pcf reduction in dry density and a 0 to 4 percent increase in optimum water content. The addition of more lime beyond the modification optimum percentage, i.e. 8 percent versus 4 percent, had only a minor additional effect on reducing the maximum dry unit weight and increasing the optimum water conditions.

35. A comparison of optimum water contents and PL shows that for these compaction efforts the optimum water content of the natural soil exceeds its PL. However, after adding lime, the optimum water content is substantially less (10-20 percent) than the corresponding PL.

Density-Water Content-Strength Relationships

36. Compaction of test specimens to determine optimum conditions provided an excellent opportunity to evaluate effects of density and water content on the UCT strengths of these soils. Accordingly, Figures 20-23 and Table 2 present results of lime-treated specimens cured



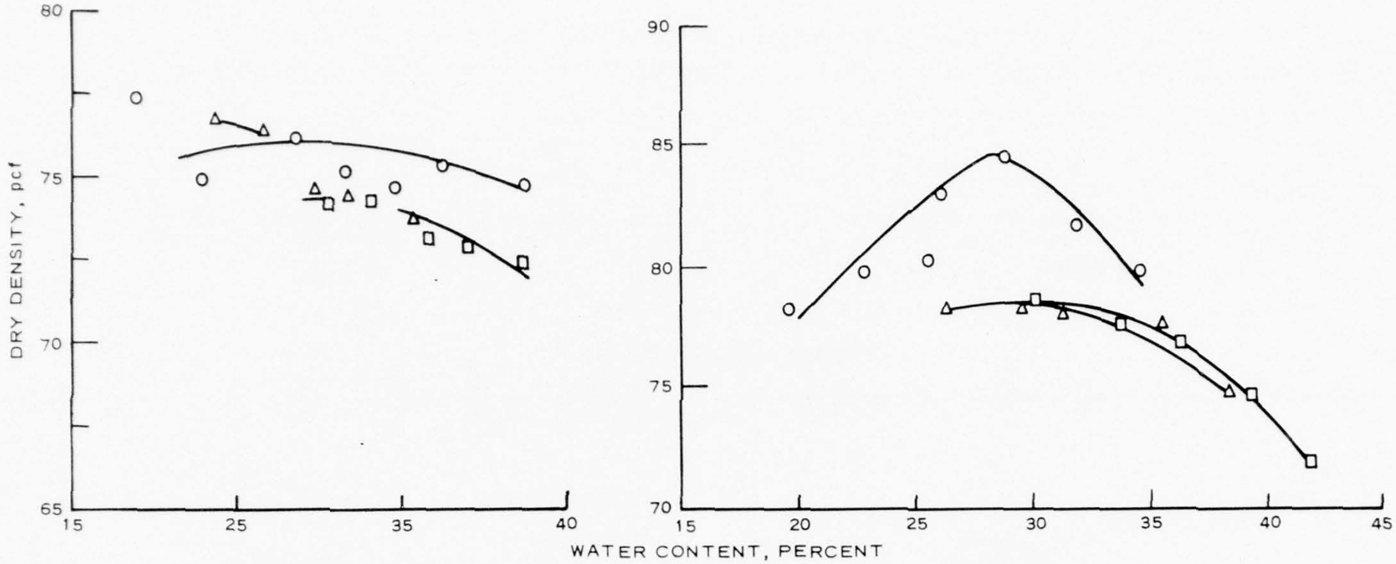
DEGONIA — LEGEND

	LIME CONTENT %	OPTIMUM WATER CONTENT %	MAXIMUM DRY DENSITY pcf
○	0	34	84.2
□	4	34	80.5
△	8	34	78.5

LITTLE RIVER — LEGEND

	LIME CONTENT %	OPTIMUM WATER CONTENT %	MAXIMUM DRY DENSITY pcf
○	0	37.0	76.8
□	4	37.5	73.5
△	8	37.0	73.0

Figure 18. Dry density-water content relationships for DeGonia and Little River levee clays plus 4 and 8 percent lime (based on 60% of standard compaction effort)



ROUNDAWAY BAYOU

LEGEND

	LIME CONTENT %	OPTIMUM WATER CONTENT %	MAXIMUM DRY DENSITY pcf
O	0	29	75.9
□	4	33	74.2
Δ	8	30	74.5

WALLACE LAKE

LEGEND

	LIME CONTENT %	OPTIMUM WATER CONTENT %	MAXIMUM DRY DENSITY pcf
O	0	28.3	89.7
□	4	29.5	83.6
Δ	8	29.0	83.4

Figure 19. Dry density-water content relationships for Roundaway Bayou levee and Wallace Lake Dam clays plus 4 and 8 percent lime (based on 60% of standard compaction effort)

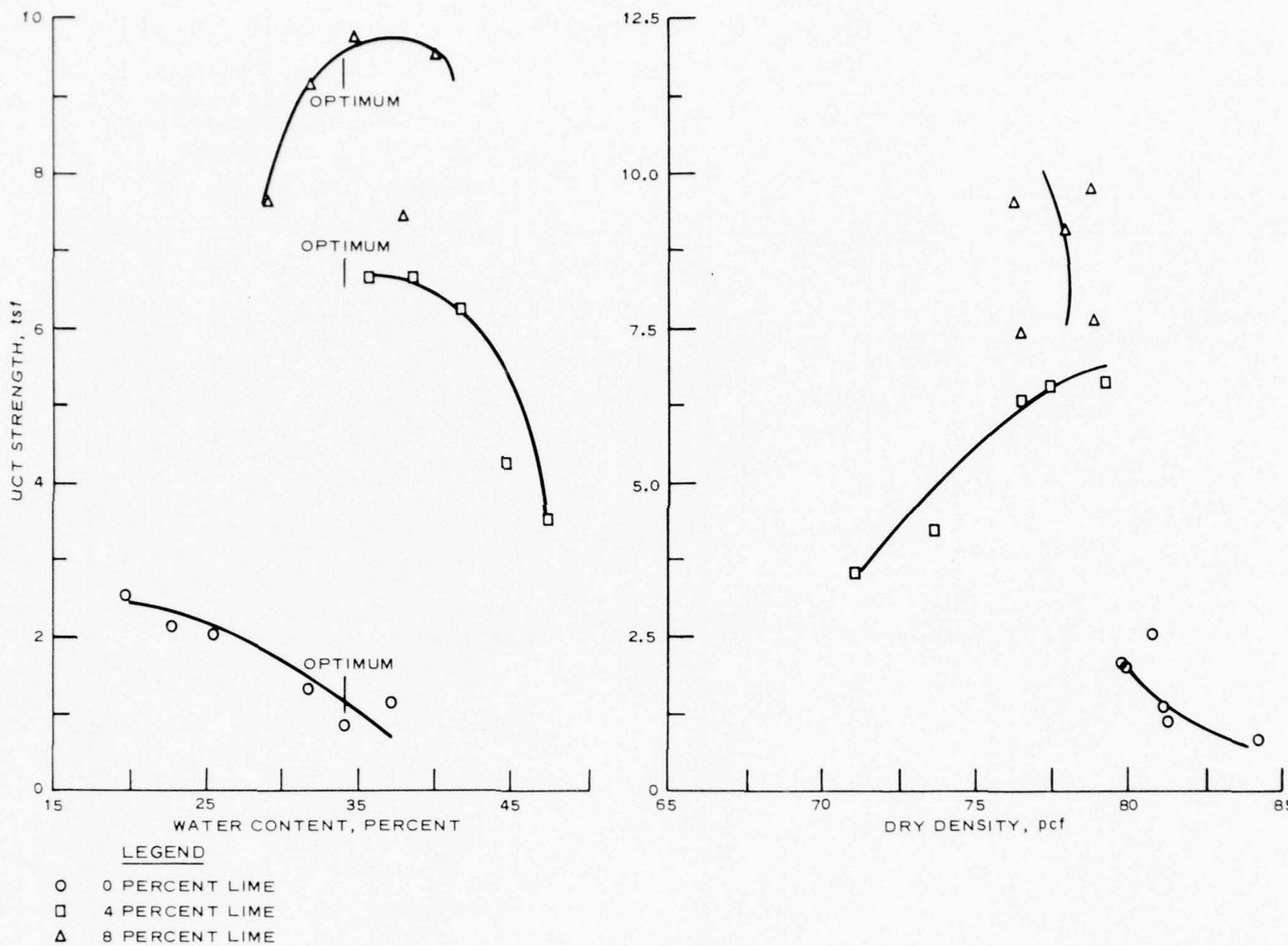


Figure 20. Water content-density-strength relationships for DeGonia clay plus 4 and 8 percent lime

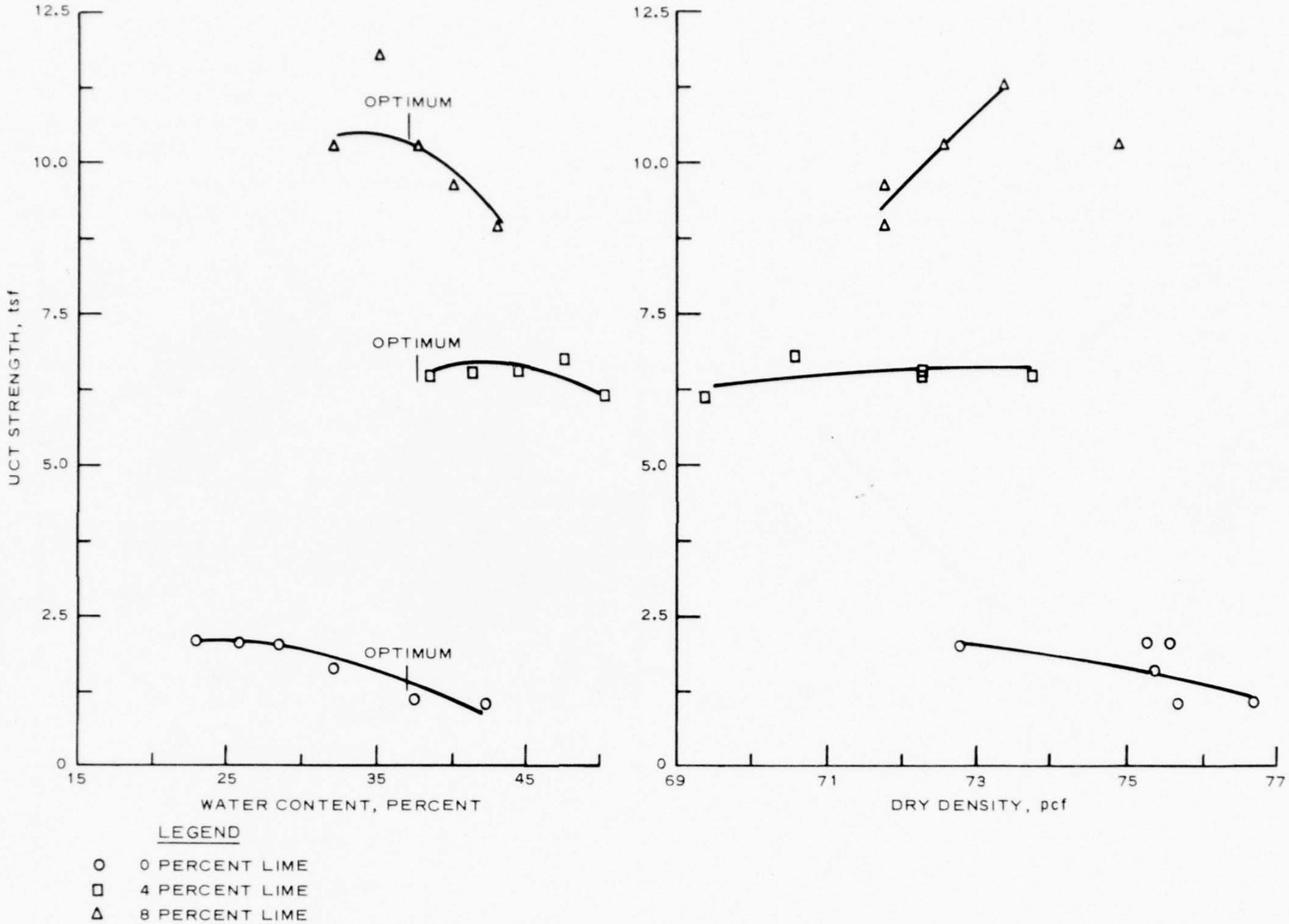


Figure 21. Water content-density-strength relationships for Little River levee clay plus 4 and 8 percent lime

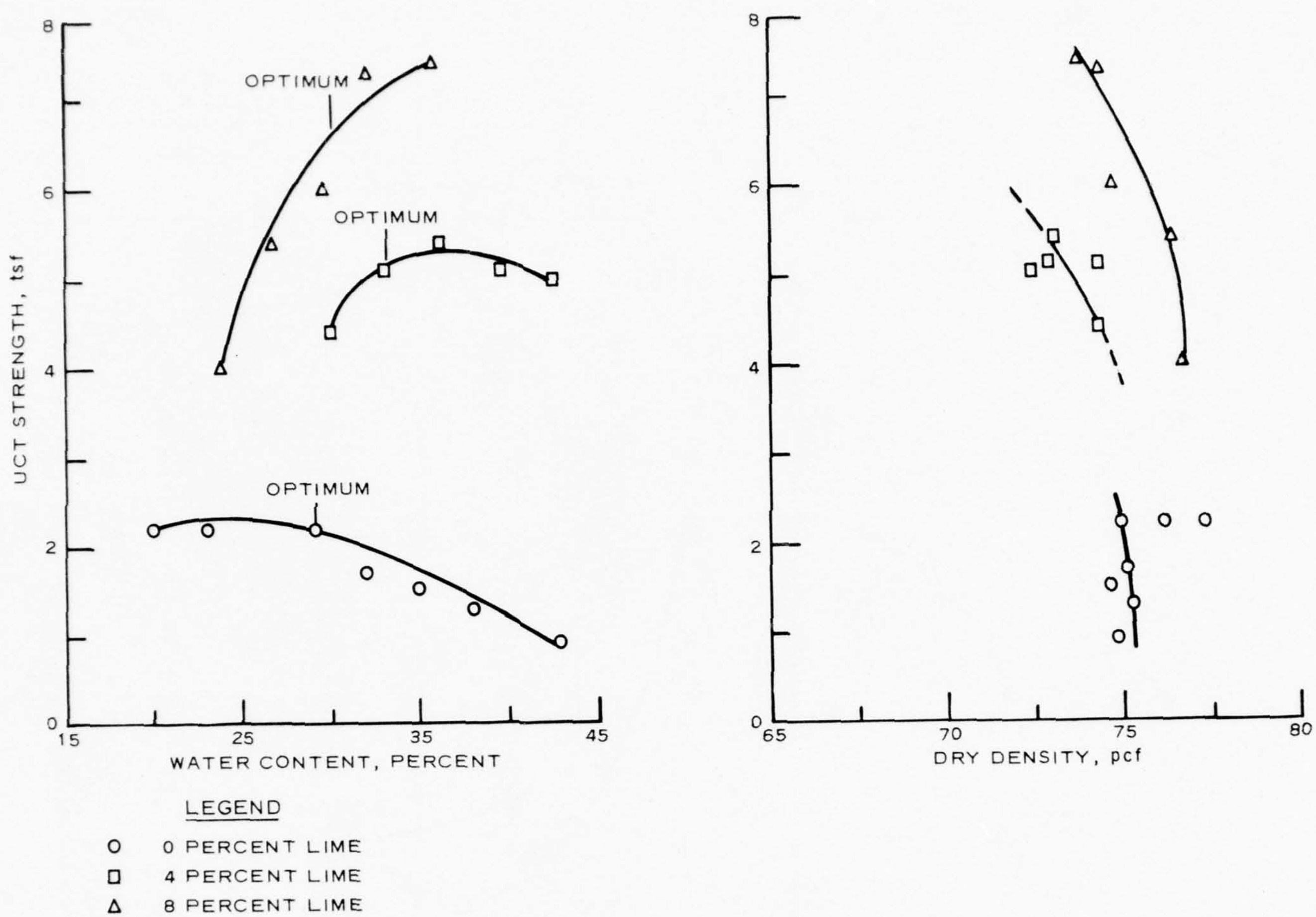


Figure 22. Water content-density-strength relationships for Roundaway Bayou levee clay plus 4 and 8 percent lime

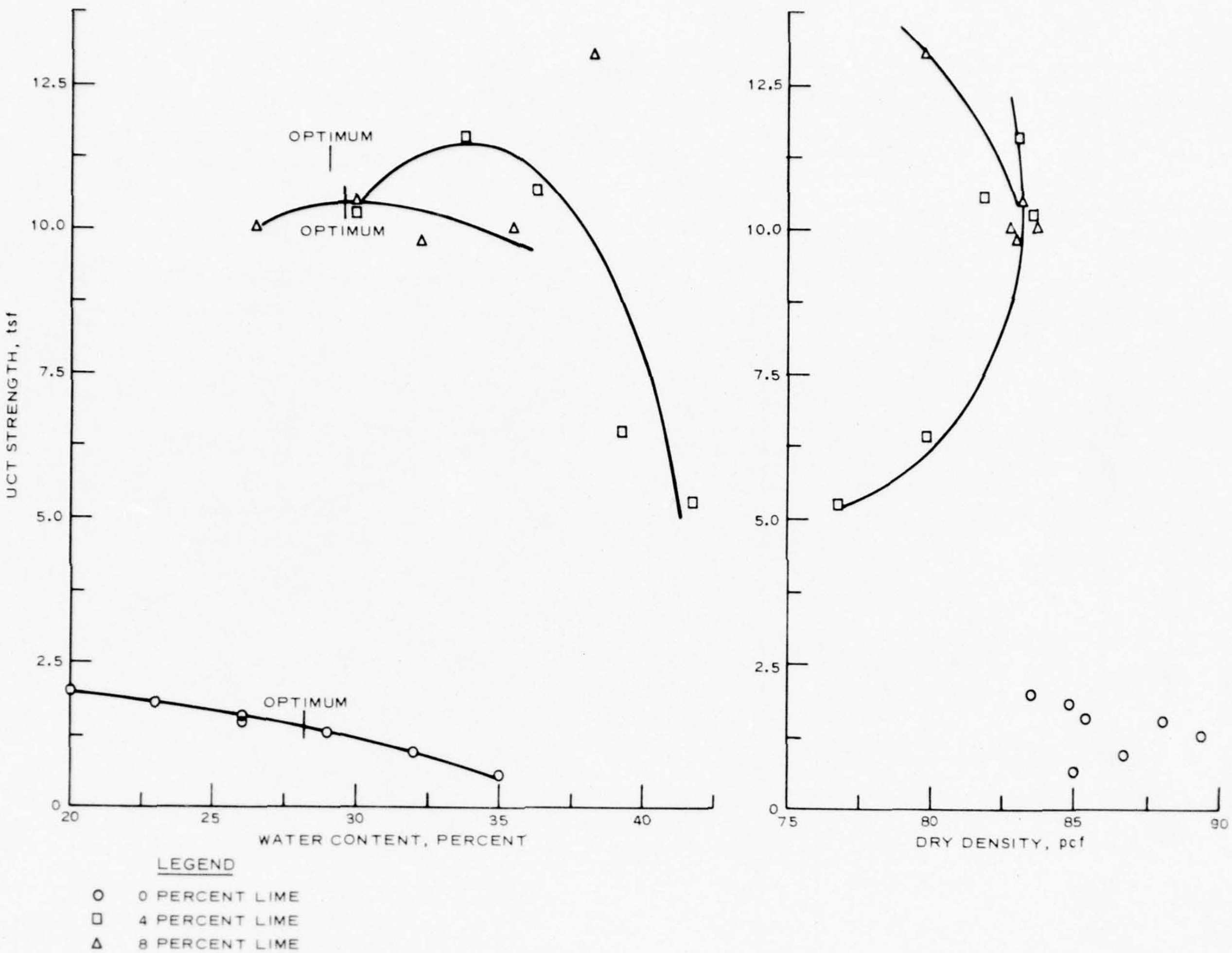


Figure 23. Water content-density-strength relationships for Wallace Lake Dam clay plus 4 and 8 percent lime

5 days at 105°F. Intuitively, increasing strength would be associated with decreasing water contents and increasing dry densities. These results show that at this low compaction effort the water content dominates the untreated soil strengths, with gradually decreasing strengths observed with increased water content. Since higher strengths were not necessarily associated with higher densities, water content must be the controlling factor, strengthwise. The following tabulation quantifies the effects of water content on the strength of these natural soils:

Soil Without Lime	UCT Strength, tsf: 2 Percent Dry of Optimum	Optimum	2 Percent Wet of Optimum	5 Percent Wet of Optimum	Percent Reduction Optimum to 5 Percent Wet of Optimum
DeGonia	1.4	1.2	0.9	No data	>25
Little River	1.6	1.4	1.25	0.9	36
Roundaway Bayou	2.2	2.2	2.0	1.8	18
Wallace Lake	1.5	1.3	1.1	0.75	42

37. When lime is added to these soils, the strength-density-water content response is greatly affected by soil type and lime content. The DeGonia clay (Figure 20) plus 4 percent lime has higher strengths with lower water contents and higher dry densities, as would normally be anticipated. Conversely, when 8 percent lime is added to this soil, higher strengths are associated with increasing water contents, instead of decreasing, with density having little effect. Similar circumstances exist for the Roundaway Bayou clay, where for 8 percent lime treatment, increasing strengths are associated with increasing water contents. These data suggest that adequate water must be present for strength-producing pozzolanic reactions to occur, and low water contents sacrifice potential lime benefits.

38. In the case of the clays from the Little River levee and Wallace Lake Dam, for 4 percent lime treatment, the clays are rather insensitive to water content changes. However, for 8 percent lime, lower strengths are associated with increasing water contents.

39. Based on these data, water content can have a substantial effect on the strength of these lime-treated soils. Water contents

above optimum, as normally occur in levee sections, may result in strengths that are half of the maximum obtainable at drier conditions. Conversely, at higher lime contents, conditions wet of optimum are beneficial in providing sufficient water for pozzolanic reactions to occur more completely. Since three out of four cases, the higher lime content, 8 percent, produces higher strengths even on the wet side of optimum than 4 percent lime, if strength is a critical consideration, additional lime added to these soils wet of optimum would produce higher or at least comparable strengths to those produced at modification optimum, i.e. 4 percent lime.

Assessment of Reactivity

Based upon standard compaction effort

40. Table 2 summarizes the compaction conditions, curing conditions, and resulting UCT strengths for the specimens tested in this program. Based upon Thompson's reactivity criteria,[14] i.e. a 3.6-tsf (50-psi) strength increase of the lime-treated material over the natural soil after curing, 28 days (896 deg-days), the results in Table 3 show that the clays from Little River and Wallace Lake, plus 4 percent lime, can be considered reactive by posting strength gains of 3.7 and 3.8 tsf, respectively. Although the levee slide clays from DeGonia and Roundaway are not considered as being reactive, their strengths were increased approximately 400 and 190 percent, respectively, thus strongly indicating that the soils were modified beneficially by adding lime.

41. Since Thompson's[14] reactivity criteria is based upon standard compaction efforts and not semicompaction (60 percent of standard), specimens of DeGonia, Little River, and Roundaway Bayou levee clays, with and without 4 percent lime, were compacted under standard effort as listed in Table 4. Although the water contents are not optimum for standard compaction effort, the strength increases were 4.95 tsf and 2.35 tsf, respectively, for DeGonia and Little River levee clays. From this data, the levee clay from DeGonia would be considered reactive ($\Delta UCT > 3.60$ tsf) at this density, while that from Little River

would not meet reactivity criteria for this water content and mellowing time.

42. Biswass'[15] correlation that a soil-lime specimen whose UCT strength is less than 7.20 tsf (100 psi) would not meet lime reactivity criteria is not appropriate for these compaction conditions. None of the soil-lime mixtures tested, even when compacted using standard effort, achieved a 28-day cured strength greater than 6.11 tsf, yet three (DeGonia, Little River, and Wallace Lake) obtained strength gains greater than 3.60 tsf (50 psi) and are considered reactive.

Based on accelerated curing tests

43. Figures 24-27 present UCT strength versus accelerated curing time (in degree-day form) relationships, while Table 2 lists these data. According to the accelerated curing criteria recommended by Dunlap et al.[11] for the SSIS, a strength increase of 3.60 tsf or UCT strength of 7.2 tsf after curing 65 hr at 105°F (176 deg-days), the data summarized in Table 3 show that accelerated curing accurately classifies the clays from Little River levee and Wallace Lake Dam as being reactive. This designation of both reactive and nonreactive by accelerated curing methods is in agreement with normal curing categorization. However, the criteria of an UCT strength of 7.2 tsf is not appropriate for these compaction conditions.

44. The results in Figures 24-27 also show that equivalent 28-day normal curing times at 105°F range from 46 to 61 hr for 4 percent lime and 31.4 to 49 hr for 8 percent lime. Obviously these equivalent curing times are somewhat lower than the recommended 65 hr suggested by Dunlap et al.[11] Because of the variation in equivalent 28-day normal curing times, Townsend and Donaghe[8] devised a method for predicting 28-day strengths using both 7-day normal and accelerated curing times and conditions. However, strength predictions (listed in Appendix D) using this procedure greatly exceed actual strengths. The errors range from 159 to 121 percent too high for 4 percent lime-treated specimens and 198 to 121 percent too high for 8 percent lime-treated specimens. However, only the reactivity of DeGonia levee clay is miscategorized as being reactive, instead of nonreactive, by this method.

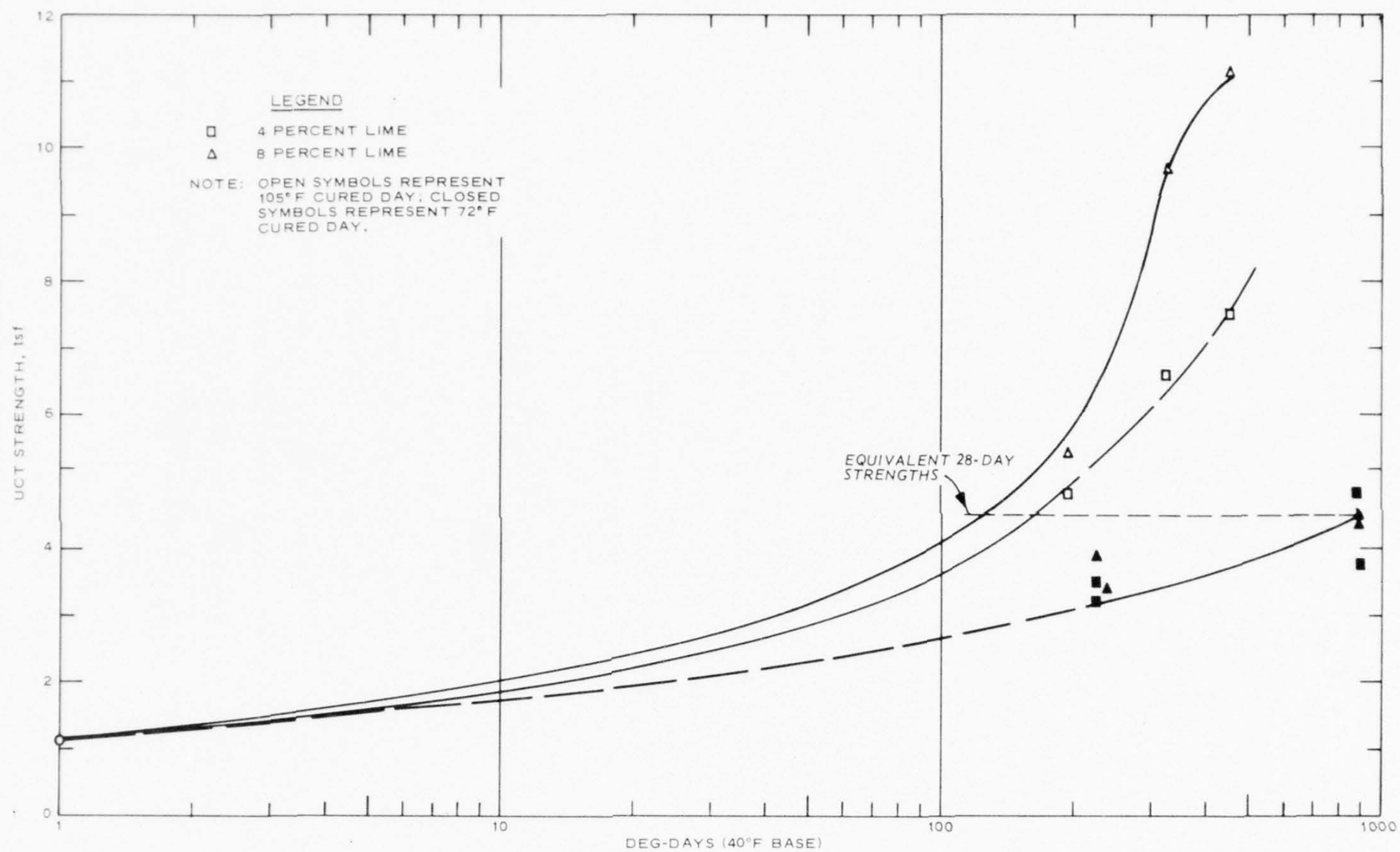


Figure 24. Degree-day strength relationship for 105 and 72°F cured DeGonia levee clay plus 4 and 8 percent lime

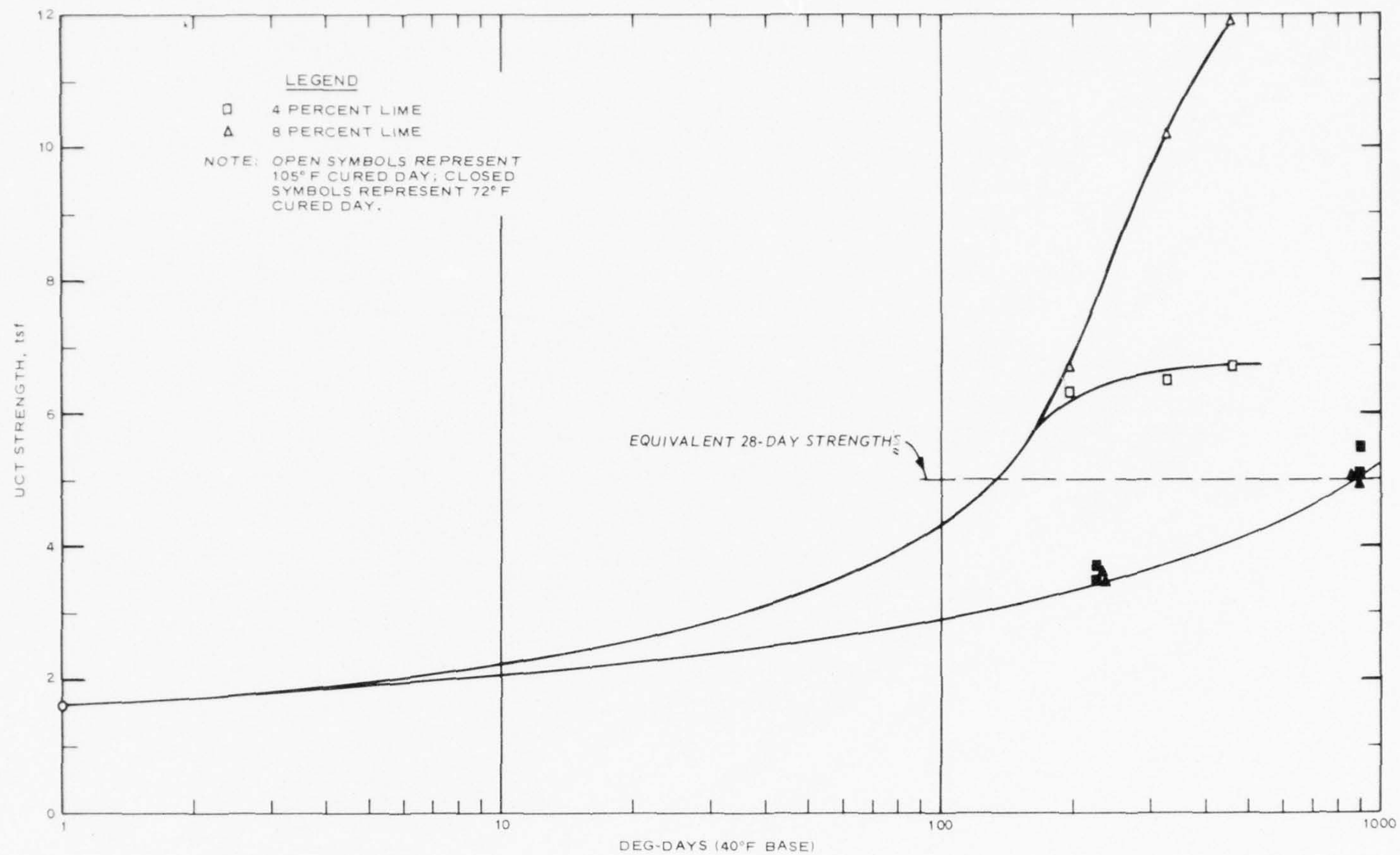


Figure 25. Degree-day strength relationship for 105 and 72°F cured Little River levee clay plus 4 and 8 percent lime

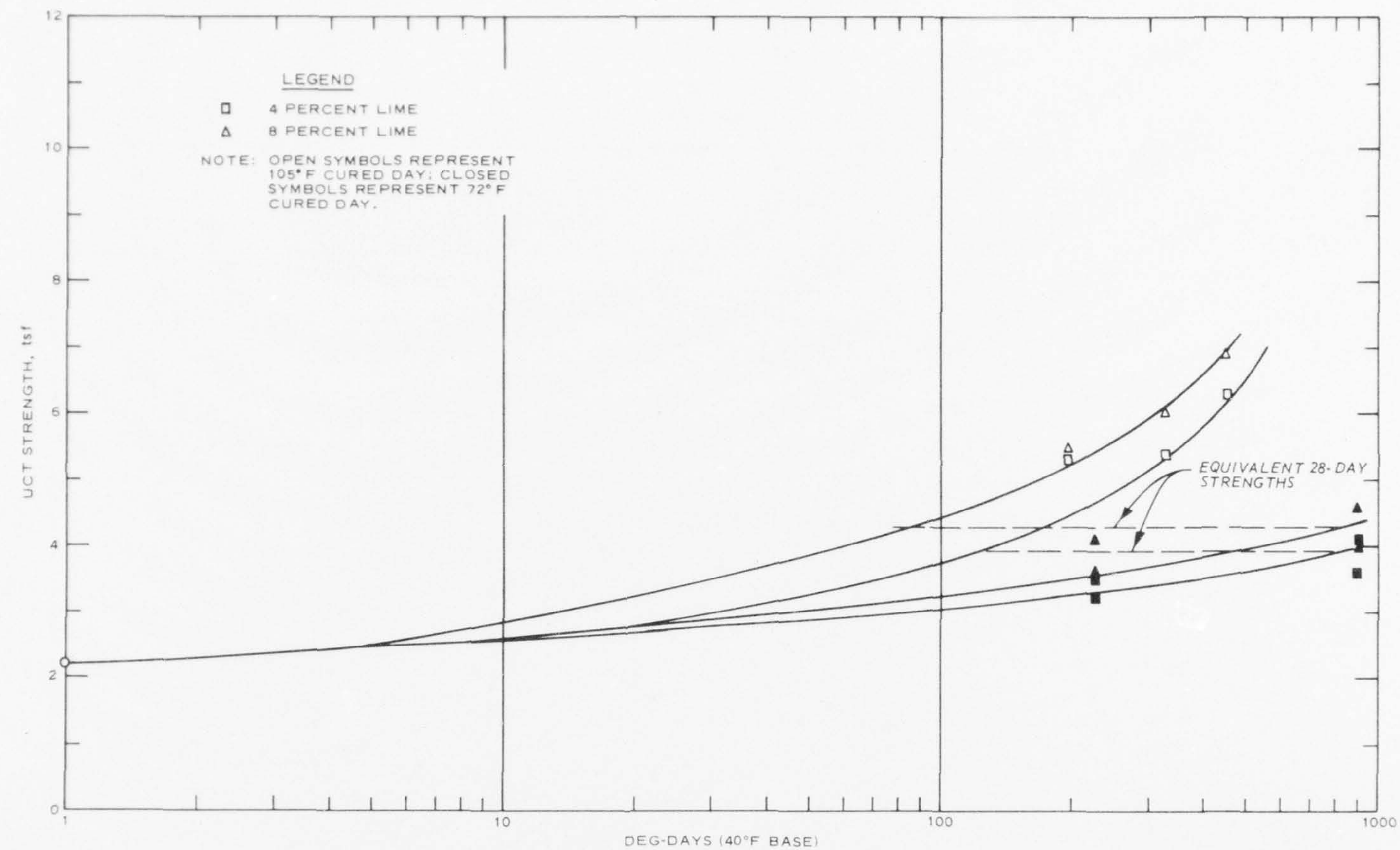


Figure 26. Degree-day strength relationship for 105 and 72°F cured Roundaway Bayou levee clay plus 4 and 8 percent lime

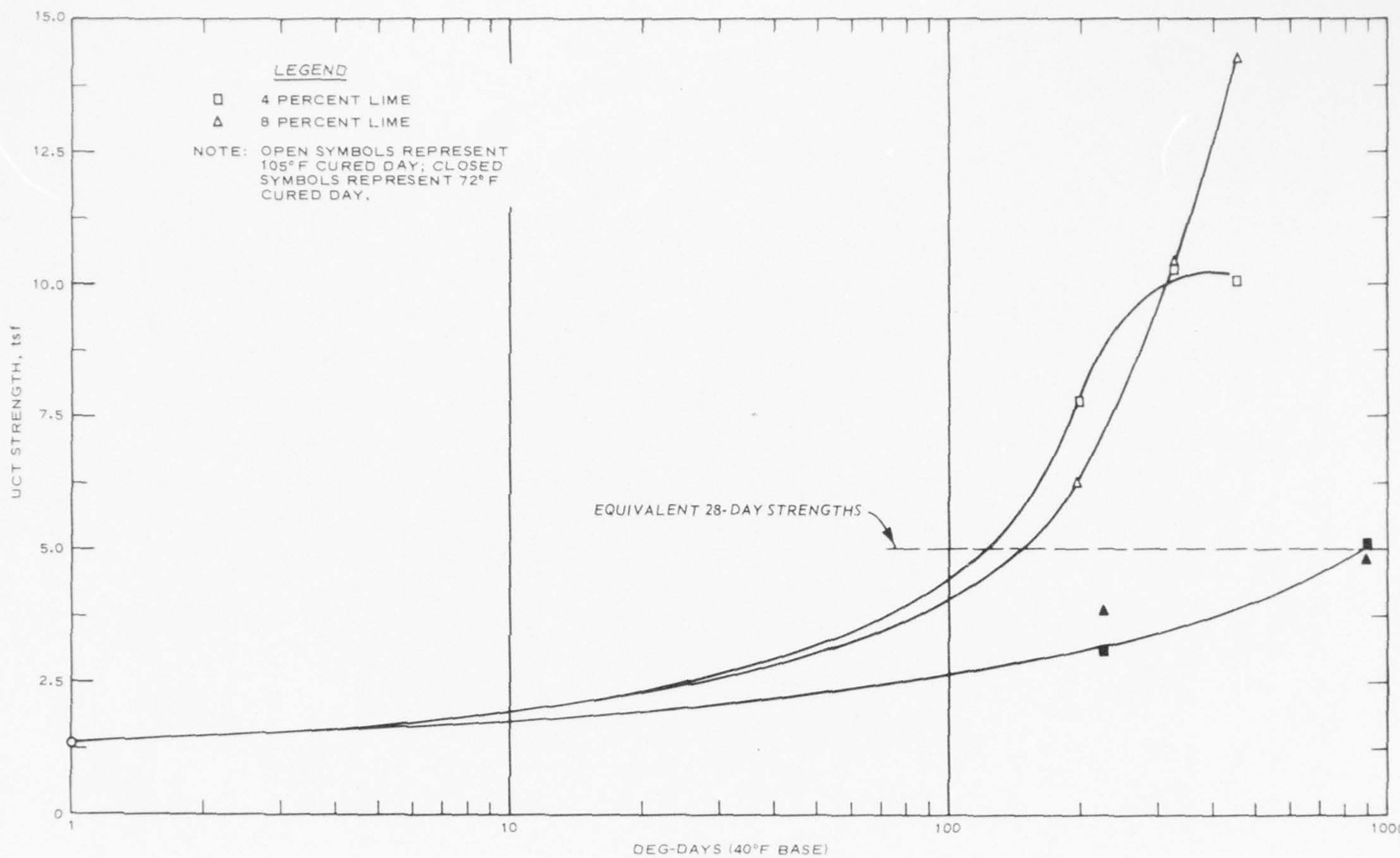


Figure 27. Degree-day strength relationship for 105 and 72°F cured Wallace Lake Dam clay plus 4 and 8 percent lime

Effects of Lime Content on Strength

45. The 28-day normal curing strengths listed in Table 2 and shown in Figures 24-27 indicate that additional lime beyond the pH percentage (4 percent lime) produced little improvement strengthwise. This finding is in agreement with those of Thompson and Eades[16] and Currin, Allen, and Little[12] who observed that the pH percentage accurately predicts the optimum stabilization percentage for 28-day normal curing. However, McDowell[21] has shown that the optimum lime content is a function of curing time, with longer curing times requiring greater lime contents. Consideration of the accelerated curing tests show that except for the Roundaway Bayou levee clay, the remaining 3 clays obtained considerably higher strengths when treated with 8 percent lime than with 4 percent. Since it is doubtful that accelerated curing at 105°F would form cementitious pozzolanic products, which would not occur under field conditions, the completeness of the reaction at 28 days must be considered. The data presented in Figure 24-27 indicate that at degree-day times equivalent to the 28-day normal curing strength, little difference exists between the 105°F accelerated curing curves for 4 and 8 percent lime. Hence, for 28 days curing, the pH test would accurately estimate the optimum lime content strengthwise.

46. In the case of the levee clay from DeGonia, Figure 24 suggests that strengths in excess of 7.5 and 11.1 tsf may be achieved for extended curing when the reactions have been driven to completeness. For curing periods longer than 28 days, higher strengths will be achieved for lime percentages in excess of the pH percentage (4 percent).

47. In the case of the levee clays from the Little River levee (Figure 25), the accelerated curing data indicate that 8 percent lime will achieve significantly greater strengths than 4 percent lime. Continued normal temperature curing of 4 percent lime-treated specimens will probably have a maximum strength of about 6.7 tsf, as these reactions have been driven to completeness after 7 days curing at 105°F.

48. In the case of the Roundaway Bayou levee clay, accelerated curing of both the 4 and 8 percent lime treatment was of insufficient

duration to achieve completeness. The results in Figure 26 suggest that maximum obtainable strengths will be in excess of 6-7 tsf, but that additional lime (8 percent) has little benefit.

49. Considering Figure 27, the data indicate that Wallace Lake levee clay plus 4 percent lime will have a maximum obtainable strength of about 10 tsf and that 7 days curing at 105°F was sufficient to drive the reaction to completeness. Also, additional lime (8 percent) should produce greater strengths.

50. These indications, based upon accelerated curing, suggest that the pH test will accurately estimate the 28-day normal curing optimum lime content, which is in agreement with previous findings. However, the DeGonia, Little River, and Wallace Lake clays will respond favorably to lime contents in excess of the pH percentage when cured more than 28 days, which is in agreement with McDowell.[21]

Effect of Compaction Delay on Lime-Treated Levee Clays

51. One problem encountered during construction will concern the effect of delay in compaction after mixing lime with the soil. Accordingly, Table 4 and Figure 28 summarize the effects of compaction delay on strength and density. These data show that the longer the mellowing time, the lower the density and corresponding strength. The greatest decreases occur during the initial 24 hr, with perceptible but insignificant changes occurring with longer mellowing times. The levee clay from DeGonia exhibited a 30 percent strength decrease over 24 hr, while the Roundaway Bayou clay lost about 75 percent due to delaying compaction 24 hr.

52. Similar results have been obtained by Mitchell and Hooper[22] and Howard and Bara.[19] Mitchell and Hooper found that a 24-hr delay between mixing and compaction led to an 8-pcf density decrease and 30 percent strength decrease over specimens compacted immediately after mixing. According to Howard and Bara, the maximum strength and density reductions occur during the initial 8 hr of mellowing time. These reductions in density and corresponding reduction in strength are

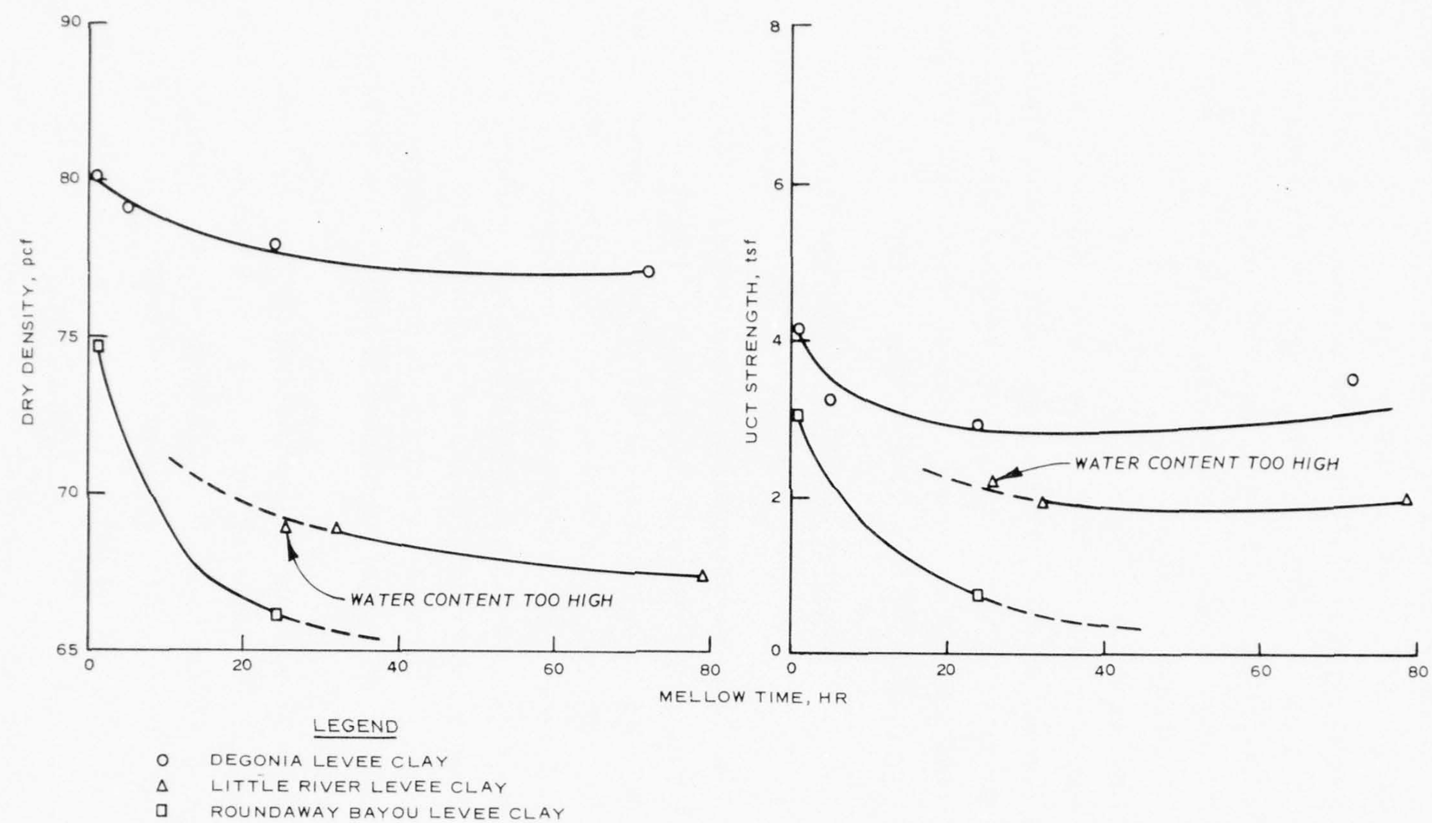


Figure 28. Effect of mellow time on density and strength of DeGonia, Little River, and Roundaway Bayou levee clays plus 4 percent lime

attributed to granulation of the loose soil particles by weak cementation as the soil mellows. Both investigative teams show that if specimens were compacted to the same density, approximately equal strength could be obtained for specimens with different mellowing times, up to 72 hr. Hence, delay between mixing and compaction is not detrimental except for additional costs to provide extra compaction to achieve comparable higher densities where delay was minimal.

Assessment of Durability by Immersion

53. Table 4 and Figure 29 summarize the effects of 24-hr immersion on specimens of natural and 4 percent lime-treated clays from DeGonia, Little River, and Roundaway Bayou levees. Applying the SSIS durability criteria of Dunlap et al.[11] of a residual strength of 2.16 tsf (30 psi), after immersion only the clay from DeGonia would meet this criteria. However, it should be mentioned that this criteria is for modified subgrades and specimens subjected to standard compaction effort. Only one specimen, Little River plus 4 percent lime, was compacted to standard effort and immersed after compaction. In this case, a strength increase from 1.23 tsf for 60 percent standard effort to 3.43 tsf for standard effort was achieved and durability criteria satisfied.

54. Thompson[14] has shown that prolonged exposure to water produces only slightly detrimental effects and the ratio of soaked to unsoaked compressive strength is high, approximately 0.7 to 0.85. For the DeGonia, Little River, and Roundaway Bayou levee clays, the ratios of immersed to unsoaked compressive strengths were 0.86, 0.63, and 0.47, respectively. For the Little River clay compacted under standard effort, the ratio was 1.03, which of course emphasizes the effect of density. While these ratios are somewhat lower than those reported by Thompson, the differences are attributed to density.

55. A comparison between untreated and 4 percent lime-treated immersed strength dramatically demonstrates the beneficial effects of lime. The untreated specimens were extremely weak, with UCT < 0.1 tsf; in fact, the Roundaway Bayou specimen completely slaked. Conversely, the lime-treated specimens resisted the effects of immersion and

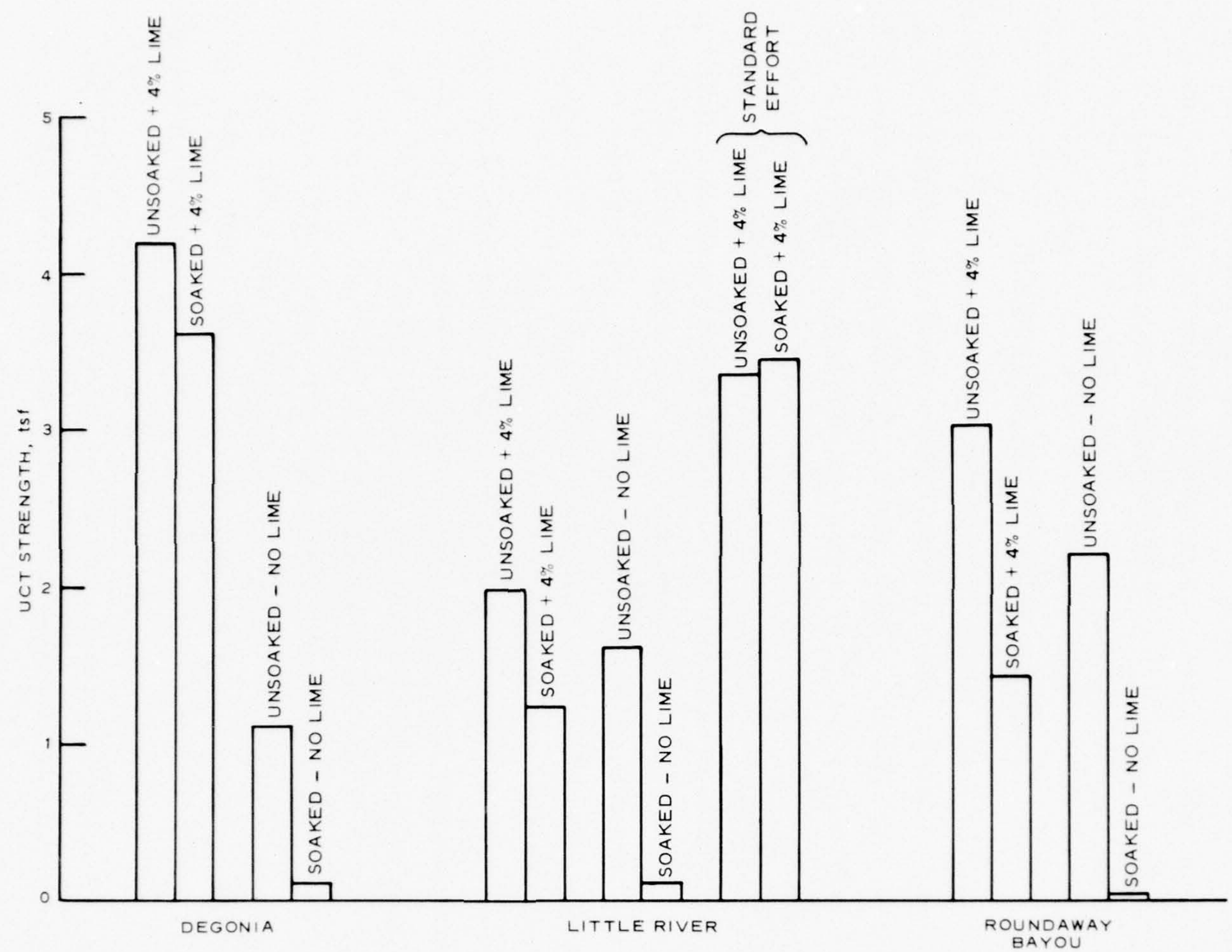


Figure 29. Summary of immersion effects on UCT strength of lime-treated and untreated DeGonia, Little River, and Roundaway Bayou levee clays

exhibited immersed strengths ranging from 1.23 to 3.61 tsf.

56. Similar results have been obtained by Mitchell and Hooper[22] and Howard and Bara.[19] Mitchell and Hooper showed that the ratios of soaked to unsoaked were about 0.7 to 0.8 for lime-treated specimens compacted wet of optimum. They also found that mellowing times up to 24 hr had an insignificant effect on strength of soaked specimens, provided the compacted densities were the same, and that soaked lime-treated specimens were roughly seven times stronger than soaked untreated specimens.

57. Howard and Bara[19] observed that three cycles of soaking and drying caused complete disintegration of lime-treated specimens for mellowing times from 0 to 72 hr. However, one specimen mellowed 72 hr but compacted to 102 percent of standard maximum density, for that mellowing time remained intact. Earlier tests on similar material treated with 4 percent lime showed that 7 days soaking reduced 7-day strengths from 15.41 tsf to 4.8 tsf. From their studies, they concluded that cyclic wetting and drying would cause surface deterioration unless protection was provided.

Effect of Excess Water During Mixing

58. Most construction procedures recommend adding significant amounts of water after mixing to obtain a good distribution of lime. In fact, in slurry applications of lime, considerable water is present. Inadvertently, these field conditions were simulated during batching Little River levee clay plus 4 percent lime mixtures for mellowing time and immersion tests listed in Table 4. Water was added to the soil-lime mixture in excess of the LL; the free water after several hours of mellowing was removed; the mixture was air-dried for 26 hr, then broken up; and the specimens were compacted. A comparison of data in Tables 2 and 4 indicates that 28-day strengths dropped from 5.3 tsf to 2.0 tsf. However, some of this decrease can be attributed to mellowing time, as well as to lower density and higher water content of the excess mixing water specimens. When the specimens were compacted to a higher density, more nearly representing those in Table 2, the strength reduction was only from 5.3 to 3.3 tsf, which when considering mellowing time makes

the effect of this field simulation procedure less detrimental. While the water content-strength relationships (Figure 21) indicate sufficient water must be present for optimizing strength potential of lime treated, most levee clays in situ possess adequate water; in these situations, achieving high densities is of critical importance in obtaining strong durable mixes. Therefore, unless dusting is a problem, the decision to add water to soil-lime mixtures or slurry applications to obtain a good distribution of lime throughout the mixture must be tempered against what effect excess water will have on the final density and mellow time.

Suitability of LMVD Levee Slide Clays to Lime Stabilization

59. One of the primary objectives of this study was to assess the feasibility of lime treatment as a remedial method for levee slide restoration. It is envisioned that restoration using lime would involve removing the failed material, treating it with lime, and replacing at the original failed slope using semicompaction. This construction would probably be performed using limited equipment. For these conditions, low densities would be obtained and no major strength improvement required, as construction would be conducted to the original failed slope. The purpose of the lime would be primarily to prevent future failures and primarily to provide sufficient modification to halt recurring cracking and sloughing due to wetting and drying and some erosion resistance. Based upon these considerations, the four levee slide clays tested all responded quite favorably to lime treatment. Even under low compaction efforts and resulting low densities, two of the soils met reactiveness criteria[14] of UCT > 3.6 tsf (50 psi), specifically clays from the Little River levee and Wallace Lake Dam, with the DeGonia clay being only slightly less than reactive. Reductions in plasticity were significant with PI's being reduced to less than 15 (except for Little River plus 4 percent), and strength increases of 300-400 percent were achieved. These modifications of the soils properties represent a major improvement in the ability to withstand future sloughing.

60. Increasing lime contents greater than the pH percentage had

very little effect on further reductions in plasticity. The normal curing test also indicated that little advantage strengthwise will be achieved by using lime contents in excess of the pH percentage. Although major strength improvements generally are of little consequence in levee slide restoration, the accelerated curing tests suggest that, except for the Roundaway Bayou levee clay, lime contents in excess of the pH percentage could produce higher strengths. However, pH percentage lime contents produce adequate strength increases.

61. Delays between mixing the lime and soil and compaction cause significant decreases in density, strength, and immersion resistance with the first 8 hr being the most critical, after which delays from 24 to 72 hr cause only slight additional reductions. The DeGonia levee clay exhibited a 30 percent strength reduction, while the Roundaway Bayou clay lost about 75 percent of its strength by delaying compaction 24 hr. These adverse strength and durability reductions are due to decreased densities occurring with mellowing and can be overcome by compacting to higher densities.

62. Considering that during critical periods of high water a lime-treated levee slide would be under water, the immersion test showed that these lime-treated levee clays can withstand soaking and still remain intact. By comparison, the untreated levee clay specimens had immersed strengths of less than 0.1 tsf or completely slaked. However, at these low densities, only the DeGonia levee clay met the SSIS durability criteria of Dunlap et al.[11] By compacting to a greater density the Little River levee clay was able to meet this durability criteria.

63. From these considerations, density plays a key role in overcoming adverse effects due to delays in compaction and withstanding immersion. In this context, it is recommended that the surface layers of lime-treated levees be compacted to high densities. If this is not possible, consideration should be given to minimizing the time between mixing and compacting these surface layers to less than 8 hr. In all circumstances, surface protection, i.e. 1 ft of topsoil, should be placed to maintain compaction moisture contents and minimize seasonal moisture variations.

Philosophy of Design Systems for Levee Restoration Using Lime

64. Figure 30 presents a flow diagram for determining lime contents and verifying lime treatment susceptibility of levee clays. The system is predicated on two situations: (a) lime treatment is to modify soil and decrease potential cracking caused by alternating shrink-swell cycles that leads to sloughing, in which case no major strength improvement is required; and (b) lime treatment is to increase strength for possible slope steepening or durability, in which case major strength improvements are required. The system uses TM 5-887-5 criteria[6] (PI > 10) to verify that lime should even be considered for soil in question. The pH test[13] is subsequently used to estimate approximate design lime content. Since the pH test does not necessarily verify that a soil will be modified or stabilized if the pH-lime percentage is added to it, modification and strength tests must be conducted.

65. If modification only (situation (a)) is desired, a PI reduction of 50 percent is considered as a reasonable demonstration that increased workability and reduced plasticity will result with lime treatment. A reduction in PI to less than 15 percent or classification of the lime-treated soil as a silt (MH or ML) will probably preclude sloughing due to cracking. If lime treatment fails to provide these basic benefits, the soil is judged nonsusceptible. Should the situation arise that the amount of strength improvement due to lime modification is desired, optional strength tests as shown can be performed. Since semicompaction will probably be used, only 60 percent of standard compaction effort is used for preparing test specimens. It is envisioned that 1.4-in.-diam UCT specimens can be prepared from the 4-in.-diam compaction specimens, in which case a suite of UCT can be performed to provide water content and density effects on strength. Alternatively, just the compaction specimen closest to optimum conditions (based upon wet densities, although dry is preferable), can be used to prepare UCT specimens. A soil-lime strength increase of 100 percent of the raw soil strength is deemed as acceptable for demonstrating a positive benefit by adding lime; if less than 100 percent, lime is judged of little benefit. This

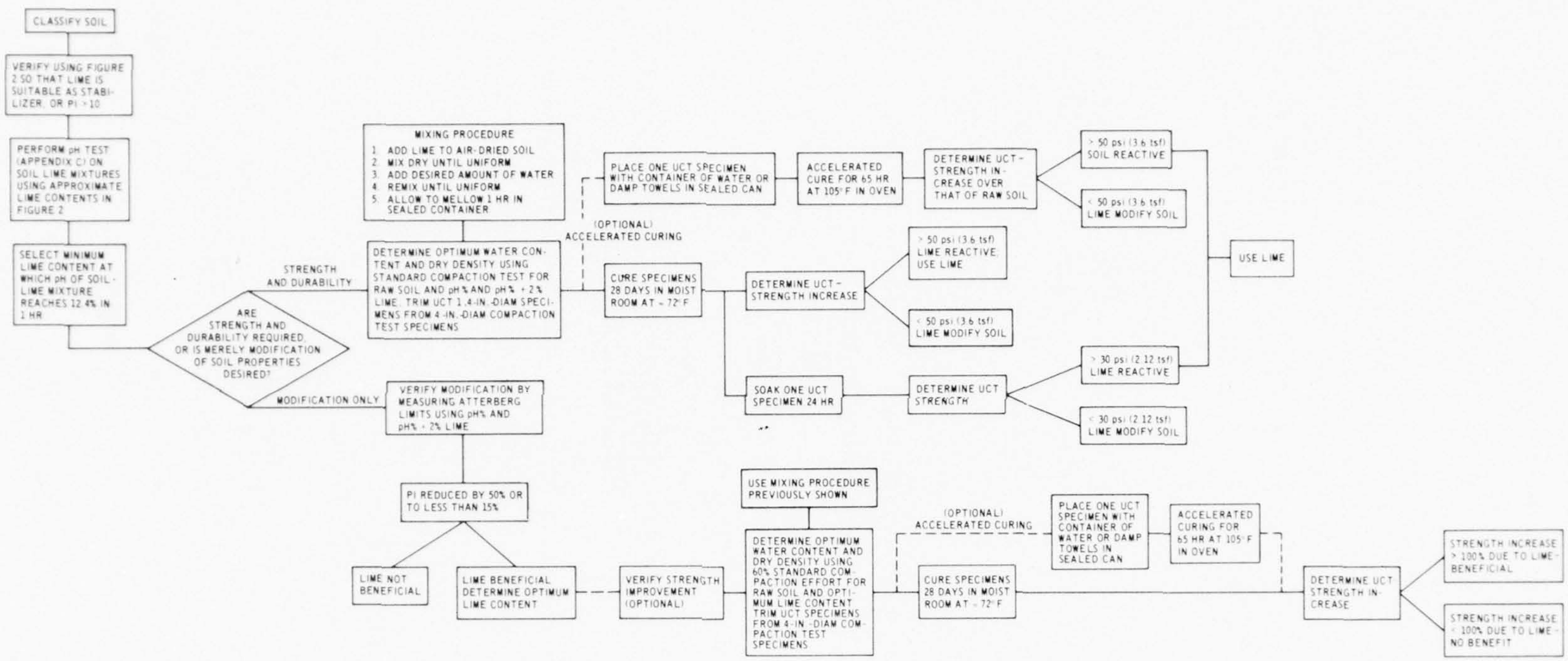


Figure 30. Flow diagram for assessing use of lime for levee restoration

strength increase can be verified by accelerated curing if expedient solutions are required, although normal 28-day curing at room temperatures is preferred.

66. If strength and durability (situation (b)) are desired, a UCT-strength increase of 3.6 tsf (50 psi) at optimum conditions and at standard compaction effort due to lime treatment and a durability of 2.16 tsf (30 psi) after 24 hr of soaking are considered as a reasonable demonstration of lime benefits. These strengths probably are more than adequate, but experience indicates that a 3.6 tsf (50 psi) UCT-strength increase provides a satisfactory performance. It is envisioned that two or three 1.4-in.-diam UCT specimens would be prepared from a 4-in.-diam compaction specimen (as described in the previous paragraph), which would be used for strength and durability testing and even accelerated curing if desired. If estimates of soaked field UCT strengths are needed, a value of one-third the laboratory unsoaked UCT strength to account for field-mixing efficiency and immersion is suggested, provided comparable densities are achieved in the field.

67. One-half to one percent additional lime above the optimum laboratory lime content should be used in the field to cover construction losses and uneven distribution.

Example of Examining Suitability of Levee Clay for Lime Treatment

68. The New Orleans District (NOD) recently evaluated lime stabilizing a soil for slope protection of the Port Sulphur levee. Lime stabilized soil was considered as a temporary, less costly alternative to concrete slope pavement, which would be unsuitable due to expected excessive settlements of the levee. From these considerations, stabilization criteria would be required to provide the durability to wave action.

69. The material evaluated was obtained from a borrow pit at Six Mile Point and consisted of approximately 71 percent clay, 26 percent silt, and 3 percent sand. Preliminary testing consisted of accelerated curing 1.4-in.-diam specimens containing 0, 5, 7, and 9 percent lime

compacted at standard effort optimum conditions for 5 days at 105°F. The results of the testing (Table 5) show that considerable benefit strength-wise was achieved by adding lime, but ΔUCT maximum was only 3618 psf, which is lower than the ΔUCT > 7200 psf criteria recommended. Also, lime contents up to 9 percent achieved successively increasing strengths. Encouraged by these preliminary results, a more detailed testing program was initiated.

70. The detailed testing program followed the strength and durability path of the flow diagram presented in Figure 30. The pH percentage was 4 percent, hence 0, 4, and 6 percent lime were selected for trials. Table 6 summarizes the compaction test results and corresponding strengths for normal and accelerated curing specimens. The compaction tests show the customary density decrease and water content increase when lime is added, with little effect being observed for lime contents in excess of the pH percentage (4 percent versus 6 percent lime).

71. The accelerated curing test results (105°F for 65 hr) show that lime successfully modified and improved soil strengths, but criteria of ΔUCT strength > 7200 psf for unsoaked specimens and a UCT strength > 4320 psf for soaked specimens were not achieved. Likewise, the 28-day normal curing test results verify that this material does not meet stabilization criteria, and only modification benefits will be obtained. Hence, although the accelerated curing tests do not accurately estimate normal 28-day strengths, for this NOD levee clay, the conclusions concerning reactiveness were the same.

72. These results show that this borrow material is unsuitable for lime stabilization, with the low UCT strengths perhaps due to the large silt content. Also, the lime contents beyond the pH percentage produce higher strengths for both normal and accelerated curing in agreement with the preliminary test results. This observation is contrary to that observed by others[12,16] but suggests that perhaps twice the pH percentage should be used for verifying lime content effects instead of the pH percentage plus 2 percent (Figure 30).

PART V: CONSTRUCTION CONSIDERATIONS

Introduction

73. The purpose of this part of the report is to provide guidance considerations concerning construction operations of levee slide restoration using lime. The initial basic steps of levee slide restoration, i.e. top soil removal and excavation of failed material, are the same whether lime is to be used or not. If restoration is to be accomplished using lime treatment, the following basic steps are required in the construction operation: soil preparation, lime spreading, mixing and watering, compaction and finishing, and curing.[23]

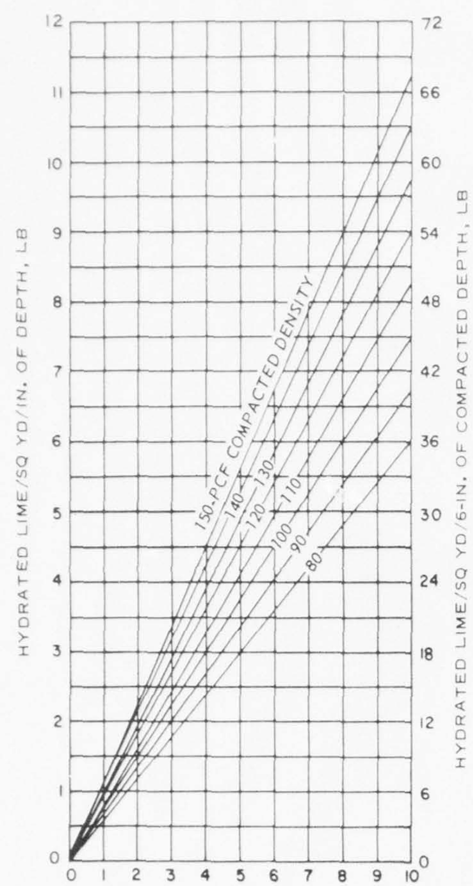
Soil preparation

74. In the case of levee restoration, soil preparation consists of removing the slide material to a mixing (or stockpile) area, depending upon the restoration scheme, after which, prior to replacing the lime-treated material, the slide surfaces should be scarified or disked.

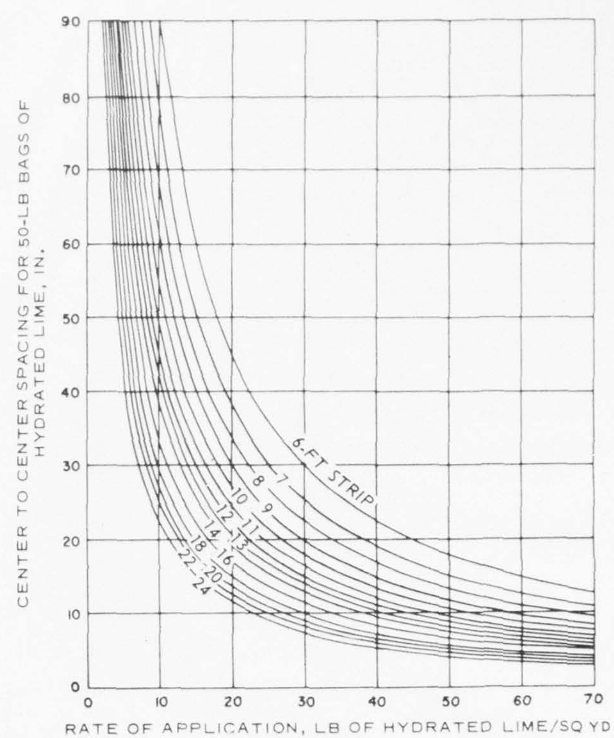
Lime spreading

75. Dry lime. Prior to mixing either from a bulk source or by bag, dry lime can be applied to the soil at a specified percent. Bagged lime is generally the simplest, but most expensive method, due to greater labor costs and slower operations caused by increased handling. Nevertheless, for small levee restoration projects, large equipment may not be warranted, and bagged lime may be the only practical method. Generally, the bags are spaced to provide the desired application percentage for the lift (which can be estimated from Figure 31), slit, and the lime dumped into piles or windrows across the lift. Spreading is then accomplished by hand raking, or a spiked-tooth harrow, or drag-pulled by tractor or truck. Immediately, thereafter, the lime is sprinkled to reduce dusting.

76. Several innovative methods with varying degrees of success have been used to spread bagged lime. The St. Louis District initially used a fertilizer spreader, but abandoned the idea after discovering too many passes were required to spread the desired amount of lime.



a. HYDRATED LIME STABILIZATION CONVERSION CHART FOR DETERMINING RATE OF APPLICATION



b. HYDRATED LIME BAG SPACING CHART

EXAMPLE: ASSUME 6-IN. LIFT (COMPACTED) PLUS 4 PERCENT LIME COMPACTED TO 110 PCF AND A WIDTH OF 16 FT.

FROM a, APPROXIMATELY 19 LB OF LIME ARE REQUIRED PER SQUARE YARD.

FROM b, 50-LB BAGS SHOULD BE PLACED ON 18-IN. CENTERS.

Figure 31. Hydrated lime stabilization and bag spacing charts (from Reference 23)

Eventually, a procedure was adopted whereby the bagged lime was emptied into a front-end loader bucket and then spread by the bucket. The Panama Canal Company reportedly used a method of spreading bagged lime by spacing the bags, slitting them, and exploding detonating primer cord that had been wrapped around the bags.

77. For large projects, where dusting is not a major problem, spreading bulk lime from large (15- to 24-ton) self-unloading transport trucks is commom practice. The newer units are pneumatically operated, and the lime is blown from the tanker compartments to a cyclone spreader or pipe spreader bar mounted at the rear.

78. For exceptionally large projects, central batching plants have been used. Self-unloading tank trucks are probably the least expensive and most practical method of spreading lime, providing the size of the project warrants their use.

79. If dry quicklime is being applied, precautions must be taken to minimize the danger of chemical burns. Some progress has been made to minimize this danger by using pelletized or granular quicklime. The advantages of quicklime are lower cost (approximately $4 per ton less than hydrated), more lime per ton (approximately 25 percent), and faster reaction times. However, justification, capitalizing on these advantages, must outweigh the hazards involved and protective equipment required.

80. Slurry application. Although dry lime application has been the most widely used procedure, the slurry method due to ease, reduced dust problems, and better distribution is becoming more popular. However, some consideration should be given to the effects of slurry treatment and water content desired for compaction (see paragraphs 34 and 36). A typical slurry mix that has been used is 1 ton of lime per 500 gal of water, which yields approximately 600 gal of slurry* containing 31 percent lime solids.[23] For control purposes the specific gravity of the

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* Assuming G_s of lime equals 2.2 and water weighs 8.345 lb/gal, then 2000 lb of lime equals 109 gal of lime, plus 500 gal of water equals 609 gal of slurry with 1 gal of slurry containing about 3.28 lb of lime.

slurry can be checked; for example, for the preceding mix proportion the specific gravity should be approximately 1.18 to 1.23.[9,24]

81. Figure 32 presents application rates of 1 ton of lime per 500 gal of water slurry for 10-ft widths per 100-ft station for a 1-ft-lift depth. For different widths or lime to water ratios, a simple proportion can be used to estimate application rates. Verification of field application rates can be made by observing the water meter on the spray bar and the speed of the tanker truck or mixing machine. Typically, mixing is accomplished in large slurry tanks located near a water source, with distribution being accomplished by tanker trucks. A new and efficient method of slurry production, which eliminates batching trucks, involves a compact jet slurry mixer. In this device, water at 70-psi pressure and hydrated lime are changed continuously in a 65:35 (weight) ratio in the jet mixing bowl, where slurry is produced instantaneously.[23]

82. Double application of lime. In cases of extremely plastic clays (PI > 50), it may be advantageous to add the lime in two applications. The first application of 2-3 percent is added first, partially mixed, and allowed to mellow from several days to a week. This mellowing period is to modify the soil by reducing plasticity and increasing workability, so that final pulverization and the second application of the remaining lime can be accomplished more easily for stabilizing the soil. Listed below are some of the advantages and disadvantages of the various lime application procedures.[9]

a. Dry hydrated lime:

(1) Advantages:

(a) Dry lime can be applied two or three times faster than slurry.

(b) Dry lime is very effective in drying out soils.

(2) Disadvantages:

(a) Dry lime produces a dusting problem, which makes its use undesirable in urban areas.

(b) The fast drying action of the dry lime requires an excess amount of water during the dry, hot seasons.

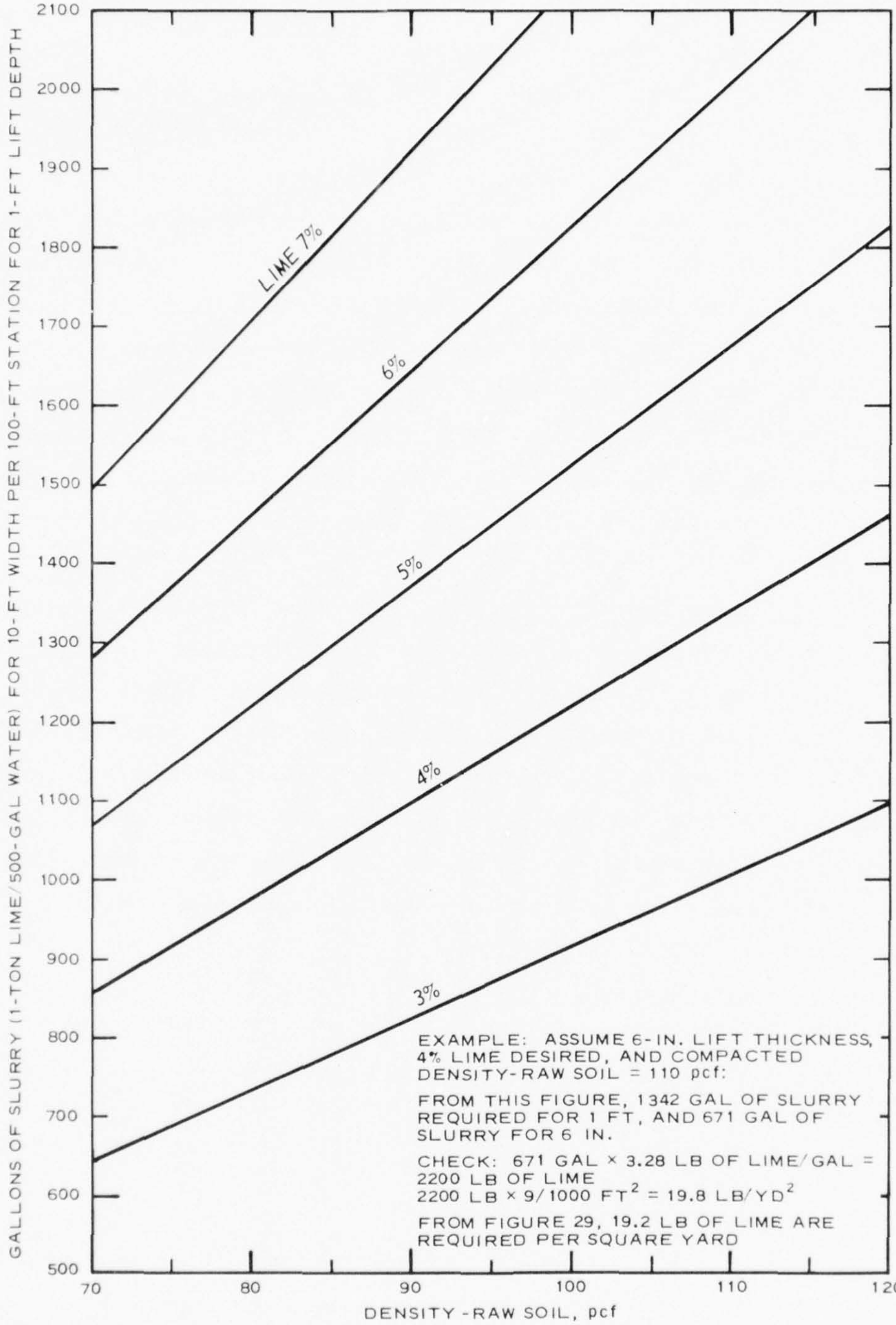

Figure 32. Application rates for 1-ton lime/500-gal slurry for 10-in. width per 100-ft station for 1-ft lift depth (after Reference 24)

b. Quicklime:

(1) Advantages:

(a) More economical as it contains approximately 25 percent more available lime.

(b) Greater bulk density so storage silos can be smaller in size.

(c) Faster drying action in wet soils.

(d) Faster reaction with soils.

(e) Faster drying so construction season can be extended, both spring and fall.

(2) Disadvantages:

(a) Field hydration less effective than commercial hydrators, producing a coarser material with poorer distribution in soil mass.

(b) The need for more water than hydrate for stabilization may present a problem in dry areas.

(c) Greater susceptibility to skin and eye burns.

c. Slurry lime:

(1) Advantages:

(a) Dust-free application is more desirable from an environmental standpoint.

(b) Better distribution is achieved with the slurry.

(c) In the lime slurry method, the lime spreading and sprinkling operations are combined, thus reducing job costs.

(d) During summer months, slurry application prewets the soil and minimizes drying action.

(2) Disadvantages:

(a) Application rates are slower. High capacity pumps are required to achieve acceptable application rates.

(b) Extra equipment is required, and thus costs are higher.

(c) Extra manipulation may be required for drying purposes during cool, wet, humid weather, which could occur during the fall, winter, and spring construction season.

(d) Not practical for use with very wet soils.

Mixing and watering

83. A key factor in obtaining satisfactory soil-lime treatments is providing adequate pulverization and intimate mixing of the soil and lime. Typically lift thicknesses of 6-9 in. are pulverized and mixed. As stated previously, double lime application may be required in highly plastic clays (PI > 50) to achieve satisfactory pulverization. Although levee slide clays generally are at water contents well above optimum, it may be necessary to sprinkle the limed soil liberally to achieve good distribution of the lime. Ideally after mixing and sprinkling, the soil-lime mixture would be at its optimum water content just prior to compaction. However, realistically, considering the environmental conditions of the LMVD, drying to optimum water content may be impractical. In these wet of optimum situations, densities and corresponding strengths and durabilities may be reduced, as explained earlier. Nevertheless, the Memphis District* discovered during lime restoration of the Joiner-Memphis levee slides that to achieve good mixing, liberal sprinkling after applying dry lime was required. Although disk harrows and grader scarifiers are suitable for preliminary mixing, high-speed rotary pulverizers are highly recommended and should be used unless the project size warrants other means. Most likely for the heavy clays encountered in levee slides, blade mixing will probably be unsatisfactory except for only minor preliminary mixing.

84. Pulverization and mixing requirements generally specify that soil-lime mixtures should be pulverized so that 100 percent passes the 1-in. sieve and 60 percent passes the No. 4, exclusive of nonslaking fractions. However, the South Dakota Highway Department[9] only requires that 95 percent, based on wet weight of pulverized soil, passes the 1-1/2-in. sieve.

Compaction and finishing

85. For maximum development of strength and durability, soil-lime mixtures should be compacted to high densities, i.e., 95 percent standard. However, in most cases of levee slide restoration only

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* Akers and Prislovsky, op. cit.

semicompaction is used, i.e., four to six passes of a crawler tractor or by routing of hauling equipment. Nevertheless under these conditions test results from this report (see paragraph 34) show that adequate modification of clays and significant strength gains can be achieved using semicompaction. Since strength durability of soil-lime mixtures are directly proportional to densities (see paragraphs 36 and 37), if possible, when using semicompaction some consideration should be given to specifying additional passes on the outer edge (surface) of the restored levee section to provide a more durable armor layer.

86. Depending upon construction sequence, breakdowns, and weather, delays between mixing the lime with the soil, placement of the soil-lime mixture, and compaction may arise. General guidance[23] suggests immediate compaction whenever possible, but delays up to 4 days are not detrimental for fine-grained soils. Test results from this investigation (see paragraph 51) show that compaction delays of 24 hr can produce strength decreases of 30-75 percent over 1-hr compaction delays. The Bureau of Reclamation[19] has shown that the initial 8 hr between adding the lime and compaction are the most critical for obtaining highest strengths, and delays between 8 and 72 hr after mixing resulted in essentially similar strengths. However, this strength loss with compaction delay can be overcome by compacting to higher densities. When long delays, i.e., 2 weeks or more are unavoidable, consideration should be given to a second application of a small amount of additional lime.

87. The construction sequence used by the Memphis District* for restoration of the Joiner-Memphis levee slides involved mixing pads where the soil and lime were mixed. After mixing, the material was transported back across the levee to be placed in the excavated slide. This procedure generally resulted in compaction delays of 1 to 2 days.

88. The construction procedure followed by the St. Louis District** was to treat each lift of material as it was excavated from the slide, hence a certain amount of mellowing occurred for each lift as the slide was being excavated. Using this procedure on small slides,

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* Akers and Prislovsky, op. cit.
** Martin, op. cit.

restoration was usually completed within 2 days.

89. Based upon these considerations, mixing and compaction may be impossible to achieve within an 8-hr period. Under these circumstances, compaction delays of several days may occur. Since density for a given compaction effort decreases with mellowing time for the first 24 hr (see paragraphs 51 and 52), it may be difficult to specify a required percent compaction in an end-result construction specification and a work-type or performance specification may be required. Nevertheless, construction sequences that hold compaction delays to a minimum should be emphasized with consideration for increased compaction for delays in excess of 8 hr, and the specification of mellowing times, except for double applications, should be discouraged.

Curing

90. For maximum strength and durability development, favorable temperature and moisture conditions plus time are required. Temperatures higher than 40 to 50°F and moisture contents of at least optimum are conducive to curing. Practically no strength-producing pozzolanic reactions occur at temperatures less than 40°F, and drying produces detrimental shrinkage cracks and also retards the chemical reactions (see paragraph 37). Generally, 7 days are sufficient to achieve sufficient strength if heavy equipment or loads are contemplated, with strength gains continuing, depending upon temperature, for several years.

Sodding and fertilizing

91. After restoration of the slide surface to grade, the surface should be fertilized and a vegetable cover established to prevent detrimental wetting and drying. The experience of the Memphis District suggests that 4 to 6 in. of topsoil is inadequate and 6 to 12 in. will probably be required. Because of the high pH of the lime-treated soil, topsoil will be required for establishing vegetative cover. The experience of the U. S. Soil Conservation Service in establishing vegetative cover over lime-treated dispersive clay dams has shown that Bermuda grass in 6 in. of topsoil will provide root penetration into the lime-treated soil; however, fescue grass did not penetrate satisfactorily. As an alternative to Bermuda, Dallis grass may be tried, with typical rates of

application being 5 to 8 lb and 8 to 12 lb per acre, respectively.

Miscellaneous Considerations

Estimating field strengths

92. Although steepening of the slopes to take advantage of increased strengths due to lime stabilization is generally not considered in levee slide restoration, situations may occur where estimates of field strengths are required. Thompson and Dempsey[25] have suggested that efficiency values, field mix strength/laboratory mix strength, of 0.65 are appropriate for mixed in-place fine-grained soils. If loss of strength due to complete immersion is considered, efficiency may be as low as 0.5. Hence, a factor of 0.33 ($0.65 \times 0.5 = 0.325$) should be appropriate if estimates of field-soaked UCT strengths from unsoaked laboratory specimens were desired.

Alternative construction procedures

93. Considering that the mechanism ascribed to these levee slides is the result of volume changes due to seasonal wetting and drying creating cracks, which when filled with water soften and subsequently sloughs, and that often a long stretch (reach) of several miles may be subjected to numerous slides, it may be desirable to surface treat or armor coat the entire levee section. In this context, two techniques, lime slurry pressure injection (LSPI)[26,27] and deep plow stabilization, would be viable methods for using lime stabilization to minimize volume changes and armor coat to prevent sloughing.

Lime slurry pressure injection

94. LSPI was initially developed to distribute lime in swelling soils to minimize volume changes and has had varying degrees of success. The technique consists of pumping lime slurry, 2.5-3.0 lb/gal of water, under pressure up to 200 psi, depending upon soil conditions, through hollow injection rods tipped with a distribution nozzle. The injection rods penetrate the soil in 12-in. intervals up to depths of 10 ft (depths to 40 ft can be achieved using specialized equipment) on spacings of 3-5 ft. When the slurry is injected into heavy clays, it migrates through available fractures and fissures creating a network of

lime seams. These seams create moisture barriers, which assist in maintaining a constant water content and thus minimize subsequent cracking. Furthermore, pozzolanic reactions adjacent to the seam probably contribute slightly to improving the performance.[28]

95. While LSPI may be difficult to evaluate by conventional laboratory tests (inasmuch as all reactions occur adjacent to the seams) and subject to controversy, considerable success using LSPI has been achieved in strengthening railroad roadbed subgrades. From these considerations, it is conceivable that LSPI could successfully treat a long levee section to provide an armor coat. However, for success it is essential that the mechanism for failure be due to volume change producing cracks and that a network of seams and fissures exist into which the lime slurry can be successfully injected.

Deep plow lime stabilization

96. While conventional soil-lime techniques using typical equipment are capable of providing high quality soil-lime mixtures to a maximum depth of 8-12 in., these techniques are inadequate for providing greater depths as desired in deep armor-coat surface treatments. Thompson[29] describes the successful use of deep plow stabilization to treat lifts 24 in. thick and suggests that the technique may possibly be extended to 36-in. lifts. The technique pioneered by the Oklahoma Department of Highways[30] consists of (a) plowing the lift to a depth of 1 ft prior to spreading the lime, (b) spreading the lime required for stabilization of the layer, (c) mixing the lime and soil with three passes of the plow to a depth of 2 ft, (d) spraying water over the lift after initial dry mixing, (e) final mixing using a deep ripper, and (f) compacting the 2-ft lift of stabilized material in one lift using either a sheepsfoot or vibratory sheepsfoot roller.

97. Densities taken and various depths, 0-8, 8-16, and 16-24 in., of stabilized lifts revealed that adequate densities >95 percent standard effort were obtained at all depths. Visual examination of the profile showed that a fairly equal distribution of lime was obtained in the upper 16 in., with a lesser amount being observed in the bottom 8 in. Utilization of this technique would be suitable for armor-coating levees,

provided that a 2- to 3-ft depth was sufficient and that heavy compaction equipment and greater than normally used semicompaction are applied.

PART VI: CONCLUSIONS

98. Based upon the soils and lime tested and procedures followed, as well as previous results reported in the literature, the following conclusions can be made.

- a. All of the soils were beneficially modified by the addition of the pH lime percent, which coincidentally was 4 percent for all the soils tested. This addition of 4 percent reduced plasticity indexes to less than 15 (except for the Little River levee clay) and achieved strength increases of 175-390 percent of natural soil.
- b. The addition of the lime pH percentage caused a decrease in maximum dry unit weight and corresponding increase in optimum water content, with little additional change in optimum conditions for higher lime contents.
- c. Compressive strength tests on compaction test specimens cured 5 days at 105°F indicated that soil type and lime content influence the effects of water content and density on strength. For the range of densities and water contents tested, the DeGonia and Roundaway Bayou levee clays plus 4 percent lime had higher strengths with increasing densities and decreasing water content, while the Little River and Wallace Lake clays were insensitive to compaction differences. However, for all four clay soils with 8 percent lime, higher strengths were associated with increasing water contents, due to the necessity of adequate water for pozzolanic reactions and full strength development.
- d. *Whether the soils are reactive or nonreactive to lime stabilization depends upon the criteria used to assess reactiveness.* Although not compacted to standard effort, the levee clays from Little River and Wallace Lake satisfied Thompson's 28-day criteria[14] (ΔUCT strengths > 3.6 tsf), as did the DeGonia levee clay when compacted to standard effort. Although equivalent 28-day accelerated curing times range from 46 to 61 hr for specimen cured at 105°F, Biswass' accelerated curing procedure[15] (65 hr at 105°F) agreed with Thompson's 28-day criteria and accurately predicted actual 28-day strengths. However, Townsend and Donaghe's[8] accelerated curing procedure erroneously predicted the DeGonia levee clay as being reactive and greatly overestimated actual 28-day strengths. The SSIS[11] criteria of 7.2 tsf after curing 65 hr at 105°F erroneously assessed all lime-treated mixtures as nonreactive, even those compacted to standard effort.
- e. The 28-day normal cured strengths showed little

improvement for lime contents beyond the pH lime percentage, thus verifying the accuracy of this test for estimating lime contents. However, the accelerated curing tests at 105°F suggest that additional lime beyond the pH lime percent can produce greater strengths and that optimum lime content is a function of curing time.

f. Delays between mixing the soil and lime and compaction (mellowing time) resulted in strength reductions of 30-75 percent and density reductions of 2.1-8.5 pcf over 24 hr, with additional mellowing times having minor additional reductions. These strength reductions due to mellowing were eliminated by compaction to higher densities. Hence, adverse effects of mellowing times up to 72 hr are detrimental only in the extra cost of compaction.

g. Immersion of specimens for 24 hr caused complete loss in strength for untreated clays, while lime-treated clays had ratios of soaked to unsoaked UCT strengths ranging from 0.86 to 0.47 corresponding to immersed strength of 1.23-3.61 tsf. However, at these low compacted densities, only the DeGonia levee clay satisfied the SSIS durability criteria of an immersed strength of 2.16 tsf. Compaction to standard effort densities should improve durability, as observed for the Little River levee clay, which increased in strength from 1.23 to 3.43 tsf and met durability criteria when compacted at standard effort.

h. The design system developed for assessing the feasibility of using lime for levee restoration recommends 28-day UCT-strength increases of 3.6 tsf and 24-hr immersion strength of 2.12 tsf at optimum conditions as stabilization criteria where strength and durability are required. A factor of 0.33 is recommended for estimating soaked field UCT strengths from unsoaked laboratory specimens. Where soil modification only is desired, a minimum PI reduction of 50 percent is deemed acceptable with 28-day strength increases of 100 percent for semicompaction conditions recommended as an optional criteria for selecting lime.

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Table 1

Summary of Accelerated Curing Times and Temperatures for Lime-Stabilized Soils

Soil	Lime Content %	28-Day Normal Cure Temperature °F	Hours of Accelerated Curing at Specified Temperature Required to Duplicate 28-Day Normal Cure Strength			28-Day UCT Strength psi	Source
			105°F	120°F	140°F		
Dyess	4.0	73	58	22	7	154.8	Biswass[15]
Altus	5.0		70	36	15	256.8	
Houma	5.0		52	25	8	67.6	
Perrin B	5.5		68	34	12	151.7	
Perrin A	6.5		97	40	20	132.4	
PRC	4.0	80	30	--	--	62.0	Drake and Haliburton[17]
PRC	8.0		72	--	--	74.0	
PRC + salt	4.0		28	--	--	62.0	
PRC + salt	8.0		28	--	--	76.0	
RMGC	6.0		31.8	--	--	42.0	
RMGC	11.0		72	--	--	44.0	
RMGC + salt	6.0		38	--	--	51.0	
RMGC + salt	11.0		36	--	--	48.0	
Kaolinite	4.5	72	--	29	--	153.2	Howard[18]
Kaolinite	6.5		--	26	--	190.4	Howard[18]
Kaolinite	8.5		--	34	--	175.0	Howard[18]
Vicksburg Buckshot	5.0		21	12	--	79.9	Townsend and Donaghe[8]
	8.0		27	13	--	81.8	
Vicksburg silt	3.0		101	28	--	58.7	
	6.0		114	35	--	68.5	

Table 2

Summary of Strength Data for Lime-Treated Clays from DeGonia, Little River, Roundaway Bayou, and Wallace Lake

Soil Specimen	Lime Content %	As Sheared Water Content %	As Sheared Dry Density pcf	Curing Time Days	Curing Temperature °F	Deg-Days 40°F Base	UCT tsf
DeGonia	0	22.8	79.78	0	72	0	2.1
		25.5	79.83				2.0
		19.9	80.75				2.5
		37.3	81.38				1.1
		31.85	81.10				1.3
		34.14	84.26				0.8
		33.7	82.55				1.25
	4	34.3	77.04	3	105	195	4.8
		35.8	79.21	5		325	6.6
		38.8	77.47				6.6
		41.8	76.56				6.2
		44.7	73.83				4.2
		47.5	71.11				3.5
		33.8	77.71	7		455	7.5
		34.0	78.88	7	72	224	3.2
		33.9	78.11	7		224	3.5
		33.7	78.11	28		896	3.7
		33.6	78.08	28		896	4.8
	8	34.1	77.14	3	105	195	5.4
		37.9	76.53	5		325	7.4
		40.9	76.25				9.5
		34.9	78.70				9.7
		29.2	78.84				7.6
		32.0	77.99				9.1
		33.6	77.16	7		455	11.1
		34.11	77.77	7	72	224	3.9
		34.13	77.54	7		224	3.6
		33.88	77.78	28		896	4.5
		33.77	77.11	28		896	4.4
Little River	0	22.9	75.3	0	72	0	2.1
		25.8	75.6				2.1
		28.4	72.8				2.0
		32.2	75.4				1.6
		37.4	76.7				1.1
		42.3	75.7				1.0
	4	37.2	74.41	3	105	195	6.3
		38.5	73.8	5		325	6.4
		41.4	72.3				6.5
		44.6	72.4				6.5
		47.4	70.6				6.7
		50.3	69.4				6.1
		36.92	73.60	7		455	6.7

(Continued)

Table 2 (Continued)

Soil Specimen	Lime Content %	As Sheared Water Content %	As Sheared Dry Density pcf	Curing Time Days	Curing Temperature °F	Deg-Days 40°F Base	UCT tsf
Little River (Cont'd)	4	36.9	74.31	7	72	224	3.7
		--	--	7		224	3.5
		34.5	75.17	28		896	5.1
		38.5	72.90	28		896	5.5
	8	37.01	73.21	3	105	195	6.7
		31.95	74.94	5		325	10.2
		35.01	73.44				11.7
		37.63	72.65				10.2
		40.53	71.84				9.6
		43.42	71.85				8.9
		40.57	73.21	7		455	11.9
		37.26	73.63	7	72	224	3.6
		37.03	73.53	7		224	3.5
		36.86	72.77	28		896	5.1
		36.79	72.81	28		896	4.9
Roundaway Bayou	0	20.0	77.21	0		0	2.2
		23.0	74.90				2.2
		29.0	76.19				2.2
		32.0	75.11				1.7
		38.0	75.28				1.3
		35.0	74.68				1.5
		43.0	74.77				0.9
	4	28.90	76.41	3	105	195	5.3
		33.3	74.30	5		325	5.1
		36.4	73.06				5.4
		30.5	74.27				4.4
		39.5	72.93				5.1
		42.5	72.42				5.0
		28.75	76.72	7		455	6.3
		28.9	75.66	7	72	224	3.5
		28.8	75.36	7		224	3.2
		28.4	75.87	28		896	4.1
		28.3	75.95	28		896	3.6
	8	28.9	75.49	3	105	195	5.5
		32.5	74.23	5		325	7.3
		35.8	73.61				7.4
		29.8	74.67				6.0
		23.9	76.70				4.0
		26.8	76.40				5.4
		28.3	75.34	7		455	6.9
		28.4	75.87	7	72	224	4.1
		28.3	75.95	7		224	3.6
		28.78	75.48	28		896	4.6
		28.70	75.44	28		896	4.0
Wallace Lake	0	20.0	83.21	0		0	2.0
		23.0	84.88				1.8
		26.0	85.29				1.6
		29.0	89.57				1.3

(Continued)

Table 2 (Concluded)

		As Sheared					
Soil Specimen	Lime Content %	Water Content %	Dry Density pcf	Curing Time Days	Curing Temperature °F	Deg-Days 40°F Base	UCT tsf
Wallace Lake (Cont'd)	0	32.0	86.67	0	72	0	0.9
		35.0	84.96				0.6
		26.0	88.17				1.5
	4	29.9	84.77	3	105	195	7.9
		30.19	83.61	5		325	10.2
		33.75	83.11				11.6
		36.32	81.95				10.6
		39.21	79.69				6.4
		41.84	76.88				5.2
		29.7	83.72	7		455	10.1
		30.0	84.21	7	72	224	3.1
		29.57	84.61	28	72	896	5.1
	8	29.80	83.81	3	105	195	6.3
		32.35	83.07	5		325	9.7
		35.54	82.79				10.0
		29.52	83.21				10.4
		38.35	79.85				13.0
		26.23	83.86				10.0
		29.50	83.21	7		455	14.2
		25.44	86.36	7	72	224	3.8
		29.9	82.92	28	72	896	4.8

Table 3

Assessment of Reactivity for DeGonia, Little River, Roundaway Bayou, and Wallace Lake Clays

Soil Specimen	Natural Soil Strength tsf	Compaction Effort	Lime-Treated Soil Strength: 28-day Curing, 4% Lime tsf	28-day Curing, 8% Lime tsf	65-hr Curing at 105°F, 4% Lime tsf	65-hr Curing at 105°F, 8% Lime tsf	Reactivity Criteria* Satisfied
DeGonia	1.1	60% standard	4.25	4.5	4.25	4.45	T_2 (4 and 8%)
	1.16	Standard	6.11				T_1
Little River	1.6	60% standard	5.30	5.0	5.90	6.10	T_1(4%), B_1(4 and 8%), T_2(4 and 8%)
	0.99	Standard	3.34				
Roundaway Bayou	2.2	60% standard	3.85	4.3	4.30	5.00	D_1
Wallace Lake	1.3	60% standard	5.10	4.8	5.75	6.75	T_1(4%), B_1(4 and 8%), T_2(4 and 8%)

* T_1 Thompson[14] - 3.6-tsf increase in 28 days over natural soil strength.
D_1 Dunlap et al.[11] - 7.2-tsf strength.
B_1 Biwass[15] - 3.6-tsf increase after curing 65 hr at 105°F over natural soil strength.
T_2 Townsend and Donaghe[8] - 3.6-tsf increase over natural soil strength using curing times Appendix D at 105°F.

Table 4

Summary of Supplemental Strength Tests for DeGonia, Little River, and Roundaway Bayou Levee Clays*

Soil Specimen	Lime Content %	As Sheared Water Content %	As Sheared Dry Density pcf	28-day Cured Strength tsf	Test Conditions
		Effects of Mellowing Time			
DeGonia	4	32.2	80.11	4.18	Mellowing time 1 hr
	4	32.4	79.16	3.24	Mellowing time 5 hr
	4	32.6	77.97	2.92	Mellowing time 24 hr
	4	32.4	77.17	3.52	Mellowing time 72 hr
Little River	4	41.7	68.93	1.96	Mellowing time 32 hr
	4	42.3	67.31	2.00	Mellowing time 79 hr
Roundaway	4	30.8	74.63	3.04	Mellowing time 1 hr
	4	38.8	66.17	0.74	Mellowing time 24 hr (accidently soaked 10 min)
		Effects of Immersion**			
DeGonia	4	32.9	80.25	3.61	
	0	44.3	77.29	0.09	
Little River	4	44.5	68.25	1.23	Mellowing time 32 hr
	0	50.0	70.99	0.09	
	4	42.0	74.25	2.43	Standard compaction effort; mellowing time 32 hr
	4	45.1	65.55	1.39	
Roundaway	4	42.8	67.56	1.43	
	0	Completely slaked			
		Effects of Density and Water Content**			
DeGonia	0	33.7	85.91	1.16	Standard compaction effort
	4	32.5	85.46	6.11	Standard compaction effort
Little River	0	36.7	82.34	0.99	Standard compaction effort
	4	50.1	67.25	2.22	60% of standard effort, mellowing time 26 hr
	4	41.3	74.37	3.34	Standard compaction effort, mellowing time 32 hr

* Insufficient material available for supplemental tests on Wallace Lake Dam clay.
** Mellowing time 1 hr unless indicated.

Table 5

Port Sulphur Slope Protection

Preliminary Tests

Sample No.	Lime Content %	Water Content %	Density pcf	Cohesion psf
1A 1B 1C	0	27	125	897 996 466 Average 946.5*
2A 2B 2C	5	32	129	926 961 924 Average 925.0*
3A 3B 3C	7	34	139	2365 1668 2260 Average 2312.5*
4A 4B 4C	9	34	139	3216 4529 4601 Average 4565.0*

* Average based on strength of two specimens closest to average; third specimen not in agreement, thus not included in average.

Table 6

Port Sulphur Slope Protection

Test Results

Sample No.	Wet Density pcf	Water Content %	Dry Density pcf	Rapid Curing: Cohesion psf	Rapid Curing: Cohesion After Soaking psf	28-Day Curing: Cohesion psf	28-Day Curing: Cohesion After Soaking psf
			0% Lime				
A-1	120.33	20.05	100.23	114	N/T*	319	166
A-2	123.13	22.25**	100.72	N/T	N/T	379	313
A-3	121.19	22.55	98.89	96	N/T	404	N/T
A-4	120.53	23.92	97.26	122	N/T	227	219
A-5	111.99	34.14	82.87	95	N/T	56	N/T
			4% Lime				
B-1	115.59	21.07	95.47	N/T	N/T	N/T	N/T
B-2	118.06	22.55**	96.34	1111	130	645	826
B-3	118.79	23.61	96.10	1966	1140	1864	884
B-4	116.59	28.04	91.06	1263	763	1470	924
B-5	110.99	35.50	81.91	115	72	297	113
			6% Lime				
C-1	116.13	21.36**	95.69	2192	1322	2073	N/T
C-2	117.13	25.00	93.70	678	1575	1295	974
C-3	115.27	26.26	91.29	431	242	706	627
C-4	113.87	26.90	89.73	272	N/T	652	341
C-5	112.47	30.72	86.04	269	N/T	522	225

* N/T - No test, sample crumbled.

** Specimens nearest or at optimum conditions, based upon standard effort.

APPENDIX A: PERTINENT ASPECTS OF TECHNICAL SPECIFICATIONS CONCERNING LEVEE RESTORATION USING LIME, JOINER-WEST MEMPHIS LEVEE SYSTEM, MEMPHIS DISTRICT

SCHEDULE

LEVEE WORK - SLIDE REPAIRS,

JOINER TO WEST MEMPHIS, ARKANSAS - MISSISSIPPI RIVER LEVEES

ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	ESTIMATED AMOUNT
	Original 14 Slides				
1	Clearing and Grubbing	1	Job	Sum	$ 3,000.00
2	Levee Restoration	28,820	Cu Yd	$ 3.78	108,939.60
3	Hydrated Lime	2,140	Ton	38.00	81,320.00
4	Environment Protection	1	Job	Sum	2,000.00
	TOTAL				$195,259.60
	4 Additional Slides				
2	Levee Restoration		Cu Yd	4.75	
3	Hydrated Lime		Ton	46.00	
	Total Contract	42,662	Cu. Yd.	$390,763.89	

PART II - TECHNICAL PROVISIONS

SECTION 1 - LEVEE SLIDE REPAIRS

1-1. SCOPE. The work covered by this section consists of repair of one slide in the slope of a spur levee and thirteen slides in the riverside slope of the existing Mississippi River Levee in Mississippi and Crittenden Counties, Arkansas. The work includes clearing and disposal of debris therefrom; excavation of the fourteen slides; and construction of levee restoration in the slide excavation areas.

1-2. QUALITY CONTROL. The Contractor shall establish and maintain quality control for the work prescribed in this section to assure compliance with contract requirements and maintain records of his quality control for all construction operations including but not limited to the following:

(1) Clearing. Limits, extent, location, disposition of materials.

(2) Excavation of Slides. Location, depth, disposition of excavated materials, side and end slopes.

(3) Levee Restoration. Quality of lime, lime treatment of material, placement, compaction, grade and cross section.

(4) Quantity Surveys. Accuracy and timeliness.

A copy of these records and tests, as well as the records of corrective action taken, will be furnished the Government as directed by the Contracting Officer.

1-3. APPLICABLE PUBLICATION. The following publication of the issue listed below, but referred to thereafter by basic designation only, forms a part of this specification to the extent indicated by the reference thereto:

American Society For Testing and Materials (ASTM) Publication.

C 6-49 (Reapproved 1968) Normal Finishing Hydrated Lime

1-4. CLEARING AND GRUBBING. All surfaces of the slide areas where excavation is required shall be thoroughly cleared of all bushes, weeds, driftwood, heavy growth of grass, and other debris. Clearing of such surfaces shall be completed in advance of applicable excavation and levee restoration. The material excavated from the slide areas shall be grubbed as necessary to rid the material of objectionable matter. Materials resulting from clearing and grubbing operations shall be burned or removed from the right-of-way. Burning shall be accomplished in

accordance with the restrictions as set forth in the "Arkansas Water and Pollution Control Acts and Codes" as adopted by the Arkansas Pollution Control Commission, 1100 Harrington Avenue, Little Rock, Arkansas. Disposal of materials by removal from the right-of-way shall comply with all applicable Federal, State, and local laws.

1-5. EXCAVATION. The material in the slide areas shall be excavated to the approximate excavation lines indicated on the drawings. The approximate quantity of excavation at each slide area is indicated on the drawings. The final limits, lines, and depths of the excavations shall be as directed by the Contracting Officer; however, at no time shall the material in the slide areas be excavated to a slope steeper than 1V on $1\frac{1}{2}$H. The excavations shall be made in such manner as to provide drainage away from the levee. Excavation of each slide shall be performed with a dragline in such manner that will not place a surcharge within 15 feet of the edges of the slide and in such manner that material will be excavated commencing at the top of the slide and progressing downward. As applicable to each slide, excavation of a slide shall be completed in its entirety prior to restoration of the levee in the excavated area. Approximately the top four inches of material shall be stripped from the slide areas and stockpiled separately from the remainder of the excavated material. Such stripped material shall be utilized in the levee restorations except that muck material and material containing organic matter will be considered unsuitable and shall be disposed of in adjacent existing borrow pits as directed. In the event there is an excess of earth material as applicable to each slide, the excess material shall be disposed of as specified hereinabove for unsuitable material. In the event the amount of excavated earth material from the slide excavations, as applicable to each slide area, is insufficient to construct the applicable levee restoration, the Contractor shall furnish additional material, as required, from sources which are subject to the approval of the Contracting Officer. Earth materials are available in adjacent existing borrow pits, and arrangements to utilize such sources may be made with Mr. Burrell B. Fair, Chief Engineer, St. Francis Levee District of Arkansas, P.O. Box 308, West Memphis, Arkansas. Slides shall not be excavated during the nonwork season described in SP-1b without prior written approval of the Contracting Officer.

1-6. LEVEE RESTORATION. The levee shall be restored to the lines and grades indicated on the drawings by the lime stabilization method as specified hereinbelow; however, a tolerance of five-tenths of one foot above the prescribed grade and section will be allowed in the final dressing provided that any excess material is so distributed that there are no abrupt humps or depressions in the surfaces. Immediately prior to placement of fill material, the slopes of the slide excavations shall be thoroughly roughened and the foundation to receive embankment shall be broken by discing to a minimum depth of 6 inches. Partially completed fill shall be kept thoroughly drained. No fill shall be placed on frozen ground nor shall frozen material be placed in the fill. Embankment materials shall be placed in layers 8 inches, plus or minus

AD-A075 787 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/13
USE OF LIME IN LEVEE RESTORATION.(U)
SEP 79 F C TOWNSEND
UNCLASSIFIED WES-GL-79-12 NL

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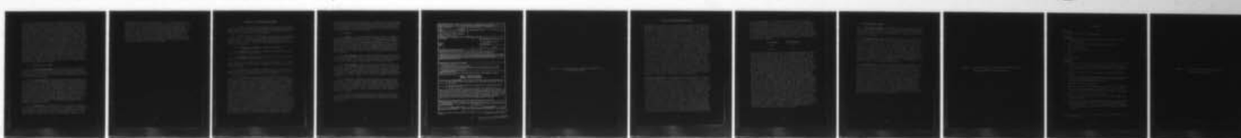

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one inch, in thickness prior to lime treatment and compaction. Each layer and the broken foundation for the embankment shall be treated with lime conforming to ASTM C 6 at the rate of 25 pounds per square yard, and the lime shall be thoroughly mixed with the soil by discing with a disc of sufficient size to penetrate the next lower layer. Water shall be added, after the lime is spread, in the amount directed by the Contracting Officer as necessary to insure that the material will receive a reasonable degree of compaction. After the lime is thoroughly mixed with the soil and water has been added as necessary, the surfaces shall be compacted by at least four passes of a crawler-type tractor weighing at least 20,000 pounds and exerting a unit tread pressure of at least 6 pounds per square inch or other approved compaction equipment which will attain comparable compaction. A pass shall consist of one complete coverage of the surface of a layer by the treads of the tractor or other approved compacting equipment. Layers shall be started full out to the slope stakes, except for the four-inch blanket specified hereinbelow, and shall be carried substantially horizontal with sufficient crown or slope to provide satisfactory drainage during construction. The final approximate four inches of the slope of the levee restoration shall be constructed of material as specified therefor in 1-5 and shall not be lime treated. Compaction of such material shall be as specified hereinabove for the lime treated layers.

1-7. MEASUREMENT AND PAYMENT.

1-7.1 Clearing and Grubbing. Payment for clearing and grubbing will be made at the contract lump price for "Clearing and Grubbing," which price and payment shall constitute full compensation for clearing, grubbing, disposal of debris, and all operations incidental thereto; all as specified in this section.

1-7.2 Levee Restoration. Levee restoration will be measured for payment by the cubic yard and quantities will be determined by the average end area method. The basis for measurement will be cross sections of the areas to be filled taken immediately prior to filling operations and the theoretical gross cross sections from the grades, side slopes and other dimensions indicated on the drawings. Payment for levee restoration will be made at the contract unit price per cubic yard for "Levee Restoration," which price and payment shall constitute full compensation for excavation of the slide areas; mixing the lime with the earth materials including furnishing and applying water as necessary; construction of the levee restoration embankment; fertilizing and sodding as specified in SECTION 2 - FERTILIZING AND SODDING; and all operations incidental thereto.

1-7.3 Hydrated Lime. Hydrated lime will be measured for payment to the nearest 0.1 ton. For the purpose of measurement and payment, one ton is equal to 2,000 pounds. The lime will be measured in the carrying vehicles on certified scales at the Contractor's expense. In the event the lime is furnished in bags, the net weight as packed by the

manufacturer will be used for measurement. In the event the lime is transported by rail to a railpoint near the sites of the work and thence to the sites of the work by truck, railroad shipping weights may, at the discretion of the Contracting Officer, be used for determining the quantity of lime to be paid for. Certified copies of scale weights or copies of freight bills, or certification of weights acceptable to the railroad company for freight charge purposes shall be furnished the Contracting Officer with invoices. Payment for hydrated lime will be made at the contract unit price per ton for "Hydrated Lime," which price and payment shall constitute full compensation for furnishing, delivering, and unloading the lime at the job sites.

SECTION 2 - FERTILIZING AND SODDING

2-1. SCOPE. The work covered by this section consists of furnishing all plant, labor, equipment, and materials, and performing all operations necessary for fertilizing and sodding all surfaces of the prescribed levee restorations in the slide areas.

2-2. QUALITY CONTROL. The Contractor shall establish and maintain quality control for fertilizing and sodding operations to assure compliance with the contract requirements and maintain records of his quality control for all construction operations including but not limited to the following:

(1) Preparation of Surfaces. Location, smoothness.

(2) Fertilizing. Quality of materials, area fertilized, quantity applied, method of application.

(3) Sodding. Quality of materials, size of sods, source, placing, spacing, covering, compaction.

A copy of these records and tests, as well as the records of corrective action taken, will be furnished the Government as directed by the Contracting Officer.

2-3. PREPARATION OF SURFACES. Surfaces which are to be fertilized and sodded shall be cleared of all growth and vegetation and shall be graded smooth and even immediately prior to fertilizing.

2-4. FERTILIZING. After the surfaces have been prepared, but prior to sodding, the entire surface of the areas to be sodded shall be fertilized by the application of standard commercial mixture or mixtures and ammonium nitrate. The quantity and nutriment ratio of the commercial mixture or mixtures shall be such that will supply not less than 40 pounds of available nitrogen, 40 pounds of available phosphate, and 40 pounds of potash per acre. The ammonium nitrate shall contain not less than 32 percent available nitrogen and shall be applied at the rate of not less than 100 pounds per acre. The commercial mixture or mixtures and ammonium nitrate shall be applied separately, each shall be uniformly distributed over the area to be fertilized, and shall be worked into the soil by light discing immediately following the application. All commercial fertilizer used shall be mixed by the manufacturer. Field blending of two or more commercial mixtures or the blending in of concentrates to provide the specified quantities of the nutrimental elements will not be permitted, except that two or more standard commercial mixtures may be used provided that each mixture be applied separately and be uniformly distributed over the area to be fertilized. In the event the commercial mixture or ammonium nitrate is furnished in bulk, the Contractor shall furnish certified weight tickets and shall submit to

the Contracting Officer, in triplicate, a certified quantitative analysis report from a recognized testing laboratory certifying the nutrient ratio of the materials. In the event the commercial mixture or ammonium nitrate is delivered to the job site in the original containers, unopened, the analysis report will not be required.

2-5. SODDING.

2-5.1 General. All surfaces where sodding is prescribed shall be planted with living sod, sprigs, or tufts of Bermuda grass. Sodding shall be accomplished, at the option of the Contractor, either by the method specified in 2-5.2 or by the method specified in 2-5.3. Sods or tufts containing Johnson grass or other noxious grasses or weeds shall not be used. Sods, sprigs, or tufts of Bermuda grass shall be kept moist from time of removal until reset, and shall be planted as soon as practicable, but not later than 24 hours after removal from the place where growing.

2-5.2 Spot Sodding. Each sod shall have an area of not less than 16 square inches and shall have at least a 2-inch thickness of earth adhering to the roots. Sods shall be placed not more than 18 inches center to center and shall be covered with 1 to 2 inches of earth.

2-5.3 Sprig Sodding. Sprigs or tufts of sod having a minimum diameter of 1 inch and with original earth adhering to the roots shall be uniformly spread over the area to be sodded. The quantity of sod to be distributed over each square yard of area shall be at least equivalent to an area of one-tenth square yard of solid sod. Immediately following spreading, the sprigs or tufts of sod shall be thoroughly disced in and covered.

2-6. COMPACTION. Immediately after sodding operations have been completed, the entire surfaces that were sodded shall be compacted by three passes or a crawler-type tractor weighing at least 20,000 pounds and exerting a unit tread pressure of at least 6 pounds per square inch or other approved equipment. A pass shall consist of one complete coverage of the surface by the treads of the tractor or other approved compacting equipment.

2-7. PAYMENT. No separate payment will be made for fertilizing and sodding and operations incidental thereto, and compensation therefor will be included in the contract unit price per cubic yard for "Levee Restoration."

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 1

1. AMENDMENT/MODIFICATION NO.	2. EFFECTIVE DATE	3. REQUISITION/PURCHASE REQUEST NO.	4. PROJECT NO. (If applicable)
0001	73OCT04		

5. ISSUED BY CODE A38950
Department of the Army
Memphis District, Corps of Engineers
668 Clifford Davis Federal Building
Memphis, Tennessee 38103

6. ADMINISTERED BY (If other than block 5) CODE

7. CONTRACTOR CODE FACILITY CODE
NAME AND ADDRESS
(Street, city, county, state, and ZIP Code)

8.
[X] AMENDMENT OF SOLICITATION NO. DACW66-74-B-0011
DATED 73SEP28 (See block 9)
[ ] MODIFICATION OF CONTRACT/ORDER NO.
DATED (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

[X] The above numbered solicitation is amended as set forth in block 12.* The hour and date specified for receipt of Offers [ ] is extended, [X] is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:

(a) By signing and returning 1 copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) [ ] This Change Order is issued pursuant to
The Changes set forth in block 12 are made to the above numbered contract/order.

(b) [ ] The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.

(c) [ ] This Supplemental Agreement is entered into pursuant to authority of
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

*The solicitation is for Levee Work-Slide Repairs, Joiner to West Memphis, Arkansas, Mississippi River Levees.

PART II - TECHNICAL PROVISIONS
SECTION 1 - LEVEE SLIDE REPAIRS

Paragraph 1-6, LEVEE RESTORATION. The paragraph is modified to the extent specified below:

1. Use of approved pulverizing equipment will be allowed in mixing the lime and soil in lieu of a disc.

2. Mixing of the lime and water will be allowed prior to placing on the layers of earth in the restoration areas.

3. In lieu of mixing the lime and soil in place in the restoration areas, the Contractor shall have the option of mixing the materials on the adjacent berm areas or other areas approved by the Contracting Officer prior to placement thereof in the restoration areas. In such event, when mixing is completed, the Contractor shall restore the berm or other areas used to original grade and section and fertilize and sod the areas used. Such fertilizing and sodding shall conform to the requirements of SECTION 2 - FERTILIZING AND SODDING. No payment will be made for restoration or fertilizing and sodding of the areas.

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. [ ] CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT [ ] CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN ____ COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR		17. UNITED STATES OF AMERICA	
BY (Signature of person authorized to sign)		BY (Signature of Contracting Officer)	
15. NAME AND TITLE OF SIGNER (Type or print)	16. DATE SIGNED	18. NAME OF CONTRACTING OFFICER (Type or print)	19. DATE SIGNED 19

30-101-01

APPENDIX B: SPECIFICATIONS FOR SOIL-LIME EMBANKMENT FILL,
NEW ORLEANS DISTRICT

SPEC FOR SOIL-LIME EMBANKMENT FILL

EXCAVATION. The material in the slide area shall be excavated to the approximate excavation lines indicated on the drawings. The approximate quantity of excavation at the slide area is indicated on the drawings. The final limits, lines, and depths of the excavations shall be as directed by the Contracting Officer; however, at no time shall the material in the slide areas be excavated to a slope steeper than shown on the drawings. The excavations shall be made in such manner as to provide drainage away from the embankment. Excavation of the slide shall be performed with a dragline in such manner that will not place a surcharge within 15 feet of the edges of the slide or top of the cut slopes and in such manner that material will be excavated commencing at the top of the slide and progressing downward. No temporary stockpiles will be allowed on or near the crown of the dam. Excavation of the slide shall be completed in its entirety prior to restoration of the embankment in the excavated area. Approximately the top four inches of material shall be stripped from the slide areas and stockpiled separately from the remainder of the excavated material. Such stripped material shall be utilized in the surface layer of the embankment except that muck material and material containing organic matter will be considered unsuitable and shall be disposed of in adjacent areas as directed. In the event there is an excess of earth material, the excess material shall be disposed of as specified hereinabove for unsuitable material. In the event the amount of excavated earth material from the slide excavation is insufficient to construct the applicable embankment restoration, the Contractor shall furnish additional material, as required, from sources which are subject to the approval of the Contracting Officer. Earth materials are available in adjacent existing borrow pits.

EMBANKMENT RESTORATION. The embankment shall be restored to the lines and grades indicated on the drawings by the lime stabilization method specified hereinbelow; however, a tolerance of five-tenths of one foot above the prescribed grade and section will be allowed in the final dressing provided that any excess material is so distributed that there are no abrupt humps or depressions in the surfaces. Immediately prior to placement of fill material, the slopes of the slide excavations shall be thoroughly roughened and the foundation to receive embankment shall be broken by discing to a minimum depth of 6 inches. Partially completed fill shall be kept thoroughly drained. No fill shall be placed on frozen ground nor shall frozen material be placed in the fill. Embankment materials shall be placed in layers 8 inches, plus or minus one inch, in thickness. A layer of embankment material may be placed on the embankment before adding the lime or the Contractor shall have the option of mixing the lime with the soil on the adjacent downstream borrow area prior to placing these materials in layers in the embankment. The lime shall be uniformly spread, and shall be thoroughly and uniformly mixed with the soil to the approximate width and depth shown on the plans, or as directed. Any procedure which results in excessive

loss or displacement of the lime shall be immediately discontinued. Lime shall be applied on such areas as can be properly processed during the same working day. Any lime that has been exposed to the open air for a period in excess of 6 hours and lime lost or damaged before incorporation, due to rain, wind, or other cause, will be rejected; deducted from measured quantities and shall be replaced by the contractor at no additional cost to the Government. Lime mixing shall be performed by an approved plant, pugmill, or traveling device. The mixture shall be kept moist and manipulated until when tested in the field it meets the requirements as follows:

U. S. Sieves	Percent Passing
3/4"	90
No. 4	40

All soil-lime mixtures must be placed in the embankment within 5 hours after the lime is added to the soil. All soil-lime mixtures must be compacted within 8 hours after the lime is added to the soil. Mixing of lime and water will be allowed prior to placing on the layers of earth in the repaired section. Each 8" thick uncompacted layer and the broken foundation for the embankment shall be treated with lime conforming to ASTM Designation C 207 Type N at the rate of 25 (5%) pounds per square yard, and the lime shall be thoroughly mixed with the soil with a rotary pulverizer of sufficient size to penetrate the next lower layer. If lime is mixed with the soil before the placing of the soil on the embankment then the embankment layer placed previously shall be scarified prior to placing of the next layer. Water shall be added, after the lime is spread, in the amount directed by the Contracting Officer if it is considered necessary to insure that the material will receive a reasonable degree of compaction. After the lime is thoroughly mixed with the soil, and water has been added if necessary, the surfaces of each layer shall be compacted by at least four passes of a crawler-type tractor weighing at least 20,000 pounds and exerting a unit tread pressure of at least 6 pounds per square inch or other approved compacting equipment which will attain comparable compaction. A pass shall consist of one complete coverage of the surface of a layer by the treads of the tractor or other approved compacting equipment which will attain comparable compaction. Layers shall be started full out to the slope stakes, except for the four-inch surface layer specified hereinbelow, and shall be carried substantially horizontal with sufficient crown or slope to provide satisfactory drainage during construction. The final approximate four inches of the surface of the embankment slope shall be constructed of material as specified in the excavation specification and shall not be lime treated. Compaction of such material shall be as specified hereinabove for the lime treated layers.

1-7. MEASUREMENT AND PAYMENT.

1-7.1 Clearing and Grubbing. Payment for clearing and grubbing will be made at the contract lump price for "Clearing and Grubbing," which price and payment shall constitute full compensation for clearing, grubbing, disposal of debris, and all operations incidental thereto; all as specified in this section.

1-7.2 Embankment Restoration. Embankment restoration will be measured for payment by the cubic yard and quantities will be determined by the average end area method. The basis for measurement will be cross sections of the areas to be filled taken immediately prior to filling operations and the theoretical gross cross sections from the grades, side slopes, and other dimensions indicated on the drawings. Payment for embankment restoration will be made at the contract unit price per cubic yard for "Embankment Restoration," which price and payment shall constitute full compensation for excavation of the slide areas; mixing the lime with the earth materials including furnishing and applying water as necessary; construction of the embankment restoration embankment; fertilizing and sodding as specified in SECTION _____ - FERTILIZING AND SODDING; and all operations incidental thereto.

1-7.3 Hydrated Lime. Hydrated lime will be measured for payment to the nearest 0.1 ton. For the purpose of measurement and payment, one ton is equal to 2,000 pounds. The lime will be measured in the carrying vehicles on certified scales at the Contractor's expense. In the event the lime is furnished in bags, the net weight as packed by the manufacturer will be used for measurement. In the event the lime is transported by rail to a railpoint near the sites of the work and thence to the sites of the work by truck, railroad shipping weights may, at the discretion of the Contracting Officer, be used for determining the quantity of lime to be paid for. Certified copies of scale weights or copies of freight bills, or certification of weights acceptable to the railroad company for freight charge purposes shall be furnished the Contracting Officer with invoices. Payment for hydrated lime will be made at the contract unit price per ton for "Hydrated Lime," which price and payment shall constitute full compensation for furnishing, delivering, and unloading the lime at the job sites.

APPENDIX C: EADES AND GRIM'S pH TEST FOR RAPID DETERMINATIONS OF LIME REQUIREMENTS FOR LIME MODIFICATION

pH Test*

Materials:

1. Lime to be used for soil modification

Apparatus:

1. pH meter (the pH meter must be equipped with an electrode having a pH range of 14)
2. 150-ml (or larger) plastic bottles with screw-top lids
3. 50-ml plastic beakers
4. CO_2 - free distilled water
5. Balance
6. Oven
7. Moisture cans

Procedure:

1. Standardize the pH meter with a buffer solution having a pH of 12.45.
2. Weigh to the nearest 0.01 g representative samples of air-dried soil, passing the No. 40 sieve and equal to 20.0 g of oven-dried soil.
3. Pour the soil samples into 150-ml plastic bottles with screw-top lids.
4. Add varying percentages of lime, weighed to the nearest 0.01 g, to the soils. (Lime percentages of 0, 2, 3, 4, 5, 6, 8, and 10, based on the dry soil weight, may be used.)
5. Thoroughly mix soil and dry lime.
6. Add 100 ml of CO_2 - free distilled water to the soil-lime mixtures.
7. Shake the soil-lime and water for a minimum of 30 sec or until there is no evidence of dry material on the bottom of the bottle.
8. Shake the bottles for 30 sec every 10 min.
9. After 1 hr, transfer parts of the slurry to a plastic beaker and measure the pH.
10. Record the pH for each of the soil-lime mixtures. The lowest percent of lime giving a pH of 12.40 is the percent required to stabilize the soil. If the pH does not reach 12.40, the minimum lime content giving the highest pH is that required to stabilize the soil.

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* After Reference 13.

APPENDIX D: PREDICTION OF 28-DAY STRENGTHS BASED UPON ACCELERATED CURING TESTS

Summary of Supplemental Data*

Soil Specimen	7-Day Normal Cured Strength tsf	Deg-Days or Hours Curing at 105°F for Equivalent 7-Day Strengths: Deg-Day	Hr	Scale Factor K 168/hr**	Hours at 105°F Required for Equivalent 28-Day Strength 672 ÷ K	Accelerated Deg-Days Required for Equivalent 28-Day Strength Deg-Days	Predicted 28-Day Strength tsf	Actual 28-Day Strength tsf
DeGonia								
+4%**	3.35	80	29.5	5.69	118.1	319.8	6.3	4.25
+8%	3.75	74	27.3	6.15	109.2	295.75	8.5	4.5
Little River								
+4%	3.6	60	22.15	7.58	88.6	239.96	6.4	5.3
+8%	3.55	60	22.15	7.58	88.6	239.96	8.1	5.0
Roundaway								
+4%	3.35	60	22.15	7.47	90.0	243.0	4.75	3.85
+8%	3.85	48	77.72	9.48	70.88	191.97	5.2	4.3
Wallace Lake								
+4%	3.1	52	19.2	8.75	76.8	208.0	8.1	5.1
+8%	3.8	74	27.32	6.15	109.0	295.97	9.5	4.8

* After Reference 8.

** DeGonia: +4% lime; 80 deg-days at 105°F required for UCT = 3.35 tsf (is 80 deg-days (from Figure 24)).

$$80 \text{ deg-days} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{1}{(105^\circ - 40^\circ F)} = \underline{29.54} \text{ hr}$$

$K = 7 \text{ days} \times 24 \text{ hr} = 168 \text{ hr normal} \div 29.54 = \underline{5.69}$ (Scale Factor)

$28 \text{ days} \times 24 \text{ hr} \div 5.69 = \underline{118.1} \text{ hr}$

$$118.1 \text{ hr} \times \frac{1 \text{ day}}{24 \text{ hr}} \times (105 - 40^\circ F) = \underline{319.8} \text{ deg-days at } 105^\circ F$$

Enter Figure 24 with 319.8 deg-days, and read strength from accelerated curing.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Townsend, Frank Charles
  Use of lime in levee restoration / by Frank C. Townsend. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
  80, [25] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station : GL-79-12)
  Prepared for U. S. Army Engineer Division, Lower Mississippi Valley, Vicksburg, Miss.
  References: p. 78-80.

1. Levees. 2. Lime. 3. Lime soil stabilization. 4. Slides. I. United States. Army. Corps of Engineers. Lower Mississippi Valley Division. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; GL-79-12.
TA7.W34 no.GL-79-12